Louisiana Water Resources Research Institute
Annual Technical Report
FY 2014

Introduction

This report presents a description of the activities of the Louisiana Water Resources Research Institute for the period of March 1, 2014 to February 28, 2015 under the direction of Dr. John Pardue. The Louisiana Water Resources Research Institute (LWRRI) is unique among academic research institutions in the state because it is federally mandated to perform a statewide function of promoting research, education and services in water resources. The federal mandate recognizes the ubiquitous involvement of water in environmental and societal issues, and the need for a focal point for coordination.

As a member of the National Institutes of Water Resources, LWRRI is one of a network of 54 institutes nationwide initially authorized by Congress in 1964 and has been re-authorized through the Water Resources Research Act of 1984, as amended in 1996 by P.L. 104-147. Under the Act, the institutes are to:

"1) plan, conduct, or otherwise arrange for competent research that fosters, (A) the entry of new research scientists into water resources fields, (B) the training and education of future water scientists, engineers, and technicians, (C) the preliminary exploration of new ideas that address water problems or expand understanding of water and water-related phenomena, and (D) the dissemination of research results to water managers and the public.

2) cooperate closely with other colleges and universities in the State that have demonstrated capabilities for research, information dissemination and graduate training in order to develop a statewide program designed to resolve State and regional water and related land problems. Each institute shall also cooperate closely with other institutes and organizations in the region to increase the effectiveness of the institutes and for the purpose of promoting regional coordination."

The National Water Resources Institutes program establishes a broad mandate to pursue a comprehensive approach to water resource issues that are related to state and regional needs. Louisiana is the water state; no other state has so much of its cultural and economic life involved with water resource issues. The oil and gas industry, the chemical industry, port activities, tourism and fisheries are all dependent upon the existence of a deltaic landscape containing major rivers, extensive wetlands, numerous large shallow water bays, and large thick sequences of river sediments all adjacent to the Gulf of Mexico.

Louisiana has an abundance of water resources, and while reaping their benefits, faces complex and crucial water problems. Louisiana's present water resources must be effectively managed, and the quality of these resources must be responsibly protected. A fundamental necessity is to assure continued availability and usability of the state's water supply for future generations. Specifically, Louisiana faces five major issues that threaten the quality of the state's water supply, which are also subsets of the southeastern/island region priorities:

Nonpoint sources of pollution are estimated to account for approximately one-half of Louisiana's pollution. Because of the potential impact of this pollution and the need to mitigate its effects while maintaining the state's extensive agricultural base and coastal zones, continued research is needed in the area of nonpoint issues. Louisiana's regulatory agencies are addressing non-point source problems through the development of waste load allocation models or total maximum daily load (TMDL) calculations. There are serious technical issues that still require resolution to insure that progress is made in solving the non-point source problem.

Louisiana's vast wetlands make up approximately 40% of the nation's wetlands. These areas are composed of very sensitive and often delicately balanced ecosystems which make them particularly vulnerable to contamination or destruction resulting both from human activities and from natural occurrences. Understanding these threats and finding management alternatives for the state's unique wetland resources are

priority issues needing attention.

Water resources planning and management are ever-present dilemmas for Louisiana. Severe flooding of urban and residential areas periodically causes economic loss and human suffering, yet solutions to flooding problems can be problems in themselves. Water supply issues have also recently a focus of concern. Despite the abundance of resources, several aquifers have been in perennial overdraft, including the Chicot aquifer. Louisiana passed its first legislation that restricts groundwater use in the past year. Water resources and environmental issues are intricately interconnected; therefore, changes in one aspect produce a corresponding responsive change in another. Further study is needed to understand these relationships.

Water quality protection, particularly of ground water resources, is an area of concern in Louisiana. Researchers are beginning to see contamination in drinking water supplies that was not present in the past. Delineating aquifer recharge areas, understanding the impacts of industrial activities on water resources, evaluating nonpoint sources of pollution, and exploring protection alternatives are issues at the forefront.

Wastewater management has been a long-standing issue in Louisiana. The problem of wastewater management focuses primarily on rural and agricultural wastewater and the high costs for conventional types of wastewater treatment as found in the petrochemical industry.

The Institute is administratively housed in the College of Engineering and maintains working relationships with several research and teaching units at Louisiana State University. Recent cooperative research projects have been conducted with Tulane University, Texas Tech University the EPA's Hazardous Substance Research Center- South & Southwest.

During this reporting period, LWRRI continued its work on the Deepwater Horizon oil spill. The LWRRI director advised state and national agencies, conducted ongoing research on the fate of oil in the systems and organized and presented research results at local, regional and national meetings. Details of this activity are presented below in the "Notable Achievements" section of the report.

Research Program Introduction

The primary goal of the Institute is to help prepare water professionals and policy makers in the State of Louisiana to meet present and future needs for reliable information concerning national, regional, and state water resources issues. The specific objectives of the Institute are to fund the development of critical water resources technology, to foster the training of students to be water resources scientists and engineers capable of solving present and future water resources problems, to disseminate research results and findings to the general public, and to provide technical assistance to governmental and industrial personnel and the citizens of Louisiana.

The priority research areas for the Institute in FY 2014 focused on selected research themes developed in conjunction with the advisory board. These themes corresponded to the major water resource areas affecting Louisiana described in the Introduction above. Projects selected were from a range of faculty with different academic backgrounds including geological scientists, environmental engineers and water resource engineers and scientists. Supporting research in these priority areas has increased the visibility of the Institute within the State.

The individual research projects designated as Projects 2014LAXXXX, are listed below.

Project 2014LA94B – Tsai, Groundwater Recharge Estimation under Climate Change Impact for the Southern Hills Aquifer System of Southeastern Louisiana and Southwestern Mississippi

Project 2014LA95B – Deng, Identification of Critical Nitrogen Source Areas in Lower Boeuf River Watershed

Project 2014LA96B – Bargu and DeLaune, Effect of Herbicide Atrazine on Phytoplankton, Water Quality, and Ecosystem Functions in Louisiana

Project 2014LA97B – Keim and Edwards, Adaptive management of Catahoula Lake for Sediment Mobility and Control of Woody Encroachment

These projects include two projects that focus on Climate and Hydrologic Processes (Projects 2014LA94B and 2014LA97B), and two projects that focus on Water Quality (Projects 2014LA95B and 2014LA96B).

Groundwater Recharge Estimation under Climate Change Impact for the Southern Hills Aquifer System of Southeastern Louisiana and Southwestern Mississippi

Basic Information

Title:	Groundwater Recharge Estimation under Climate Change Impact for the Southern Hills Aquifer System of Southeastern Louisiana and Southwestern Mississippi
Project Number:	2014LA94B
Start Date:	3/1/2014
End Date:	2/28/2015
Funding Source:	104B
Congressional District:	6th
Research Category:	Climate and Hydrologic Processes
Focus Category:	Hydrology, Models, Methods
Descriptors:	None
Principal Investigators:	Frank Tsai

Publications

1. Beigi E., and F. T.-C. Tsai, 2014. "GIS-Based Water Budget Framework for High-Resolution Groundwater Recharge Estimation of Large-Scale Humid Regions". Journal of Hydrologic Engineering, ASCE, 19(8), 05014004, doi:10.1061/(ASCE)HE.1943-5584.0000993.
2. Beigi E. and F. T.-C. Tsai. 2015. "Comparative study of climate-change scenarios on groundwater recharge, southwestern Mississippi and southeastern Louisiana, USA". Hydrogeology Journal 23(4), 789-806. doi :10.1007/s10040-014-1228-8
3. Beigi E. and F. T.-C. Tsai, 2014 "Hierarchical BMA Analysis of Hydrologic Projections under Climate Modeling and Scenario Uncertainties", Abstract, 2014 American Geophysical Union Fall Meeting, San Francisco, California, December 2014.
4. Beigi E. and F. T.-C. Tsai, 2014 "Comparative Study of Climate Change on Groundwater Recharge", Abstract, American Society of Civil Engineers (ASCE), 2014 World Environmental and Water Resources Congress, Portland, Oregon, May 2014.
5. Beigi E. and F. T.-C. Tsai, 2014 "A Water Balance Approach to Estimate Surface Runoff and Potential Groundwater Recharge of Southern Louisiana", Abstract, US-China International Workshop on Key Processes and Regulation of Wetland Ecosystems." Louisiana State University, Baton Rouge, LA, November 12, 2014.
6. Beigi E. and F. T.-C. Tsai, 2014 "Impact of Climate Change on Groundwater Recharge of Southern Hills Aquifer System", 7th Annual Groundwater and Surface Water Resources Symposium, Louisiana Geological Survey (LGS), Baton Rouge, LA, April 18, 2014.

Problem and Research Objectives

Significantly increased emissions of greenhouse gases from anthropogenic activities has caused climate to change. As reported by the Intergovernmental Panel on Climate Change (IPCC), the global mean surface temperature and the global mean sea level have risen by 0.6±0.2 °C and by 20±5 cm, respectively since the late 19th century. Additionally, the IPCC predicted 2 to 4 °C global temperature increase and 18 to 59 cm sea level rise in the 21st century. The global warming is projected to intensify the global hydrologic cycle, alter precipitation amount, pattern and intensity, increase atmospheric water vapor, evaporation and evapotranspiration, and change groundwater recharge and runoff. Climate variation can impact on availability of groundwater through evapotranspiration and recharge processes. Because precipitation and surface water are the main sources to recharge aquifers, evaluating the impact of climate change on groundwater systems needs reliable estimation of recharge, which is important for assessing drought, water quality, groundwater availability and sustainability. Improving the understanding and modelling of climate changes on groundwater recharge have been highlighted in the last five IPCC reports. Recently, the increasing number of climate change studies with regard to groundwater resources has shown the importance of this subject. Knowledge of groundwater recharge is particularly important to regions where large demands of drinking water supplies rely heavily on groundwater, such as the Southern Hills aquifer system, southwestern Mississippi and southeastern Louisiana, USA. Reliable recharge estimation is important for efficient and sustainable groundwater resource management and for aquifer protection from rapidly expanding urbanization, drought or climate change.

This study assesses the climate change impact on groundwater recharge in humid areas using the water budget method. The HELP3 model (Schroeder et al. 1994), a water budget model, is employed to estimate potential recharge since HELP3 has been widely used to estimate recharge. To investigate the impact of climate change on groundwater recharge for a large-scale humid region, this study develops a water budget framework using HELP3 in conjunction with a geographic information system (GIS). The framework estimates potential recharge under three different emission scenarios (B1, A2 and A1FI) of two global climate models (GCMs), which are the National Center for Atmospheric Research's Parallel Climate Model 1 (PCM) and the National Oceanic and Atmospheric Administration Geophysical Fluid Dynamics Lab's (GFDL) model (Maurer et al. 2002 and Maurer 2013). The framework is applied to the area of the Southern Hills aquifer system, southwestern Mississippi and southeastern Louisiana, USA (Figure1). The historical condition in 1950-2009 is used as a baseline and is compared to the results of six climate change scenarios for three future periods: 2010-2039, 2040-2069 and 2070-2099.

Principal Findings and Significance

1. Baseline Historical Potential Recharge

The mean annual potential recharge shown in Figure 2 for the area of the Southern Hills aquifer system is considered as the baseline historical recharge for climate change comparisons. The mean annual potential recharge ranges from 0 to 857 mm. The average of the mean annual potential recharges (1950-2009) for the entire area is 227.5 mm. 45.6 % of the subdivisions have mean annual potential recharge above the average. 48.8 % of the subdivisions have mean annual

potential recharge lower than 205 mm while 40.7 % have mean annual potential recharge between 205 mm and 410 mm, and 10.45 % have mean annual potential recharge higher than 410 mm. The west of the study area (including the parishes of Adams County, Claiborne County, Jefferson County, Wilkinson County, and West Feliciana) is the recharge zone of the Baton Rouge aquifer system and shows high potential recharge historically. High potential recharge is also demonstrated in the east and central Florida parishes. Low potential recharge is demonstrated in the north and northeast of the study area.

Figure 1: Location of the Southern Hills aquifer system (bounded by a thick black line). The parish boundaries are in thin black lines.
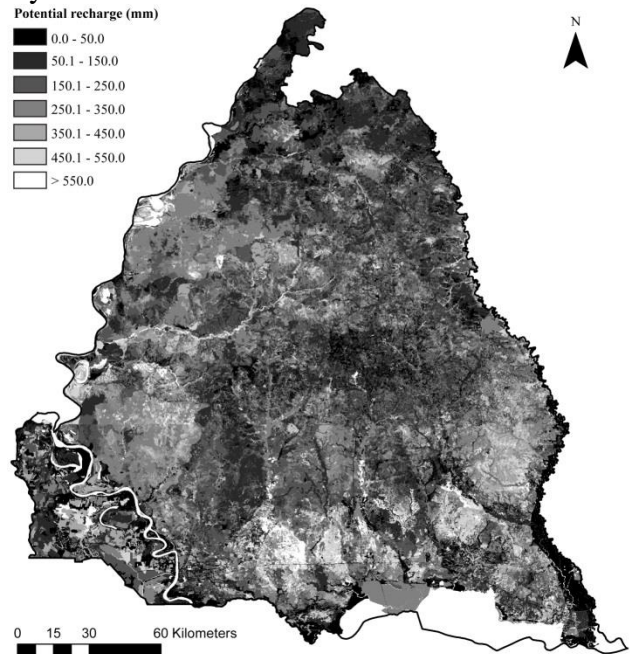
Figure 2: Mean annual potential recharge (mm) for 1950-2009 for the Southern Hills aquifer system.

2. Temporal Results

The changes in temperature and the cumulative changes in precipitation and solar radiation for individual scenarios with respect to the historical baseline (1950-2009) are shown in Figure 3. To calculate the changes for the Southern Hills aquifer system, the area-averaged values of the climate variables of all subdivisions were calculated and subtracted from the mean annual for 1950-2009. Sums of the changes over years show the cumulative changes. If changes in climate variables are negative over time, their cumulative changes will amplify this phenomenon by showing large negative values. For example, a fall of almost 10 m cumulative change in 2099 for GFDLA1F1 shows that the yearly precipitation continuously decreases from 2040 to 2099 with respect to the baseline precipitation. The differences of the cumulative changes between the scenarios become more evident over time. The cumulative changes of solar radiation projected by the PCM and GFDL models are opposite and distinguishable from the beginning of projection. After the mid-century, the cumulative changes of precipitation and the changes of temperature between emission scenarios are distinguishable, which is consistent with

the global projections (Cubasch et al. 2001). Scenarios PCMB1, PCMA2, and GFDLB1 project overall precipitation increase while the other three scenarios project overall precipitation decrease for the 21st century. Moreover, scenarios PCMB1, PCMA2, and GFDLB1 project relatively less temperature change than the other three scenarios for the 21st century.

In general, the projections of the PCM and the GFDL models begin to diverge greatly after the mid-century for the study area. This divergence is in harmony with greenhouse forcing associated with the various scenarios and starts at the point at which substantial differences between the projections by these two models begin. These differences stem from the two models' parameterizations, sensitivities and responses to greenhouse gases and other forcings (Cayan et al. 2007).

Figure 4 presents the cumulative changes in potential recharge, runoff and evapotranspiration with respect to the historical baseline scenario for each climate change scenario. It is observed that potential recharge cumulative changes follow the same trend as precipitation cumulative changes, which highlights the fact that the potential recharge in the study area is more sensitive to precipitation than temperature and solar radiation. Scenarios GFDLA2 and GFDLA1FI project significant potential recharge decrease towards the end of the 21st century. On the other hand, scenarios PCMB1 and PCMA2 project the most potential recharge increase for the 21st century. Almost all of the climate change scenarios project runoff decreases for the 21st century except for the GFDLB1. PCMA1FI projects the highest runoff reduction, followed by PCMB1. Although projecting precipitation increase for the 21st century, scenarios PCMB1 and PCMA2 show runoff decrease due to projected high evapotranspiration shown in Figure 4(c). The PCM model projects continuous evapotranspiration increase for the 21st century. However, the GFDL model does not show significant change of evapotranspiration before 2069, but has a wide-ranging evapotranspiration projection in 2070-2099.
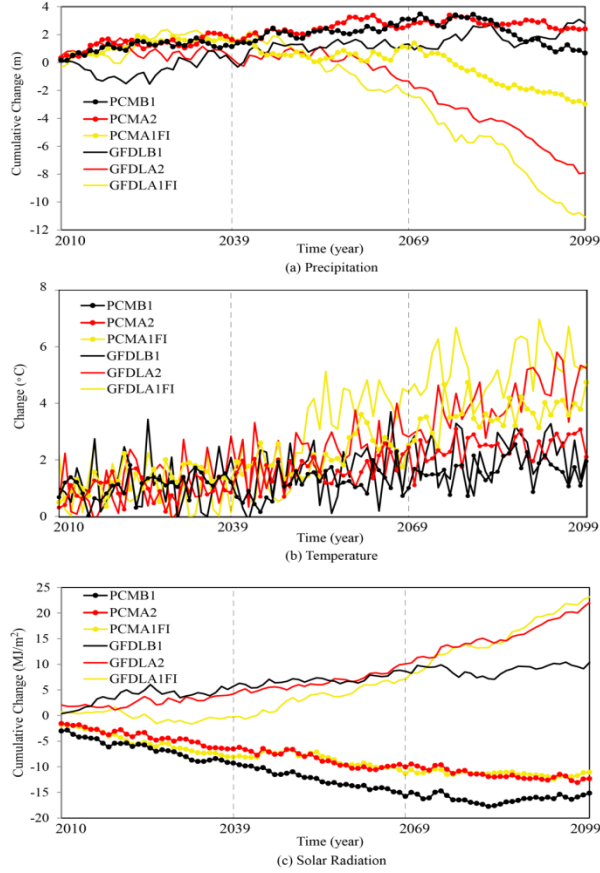
Figure 3: Cumulative changes of (a) precipitation, (b) changes of temperature, and (c) cumulative changes of solar radiation with respect to the historical baseline
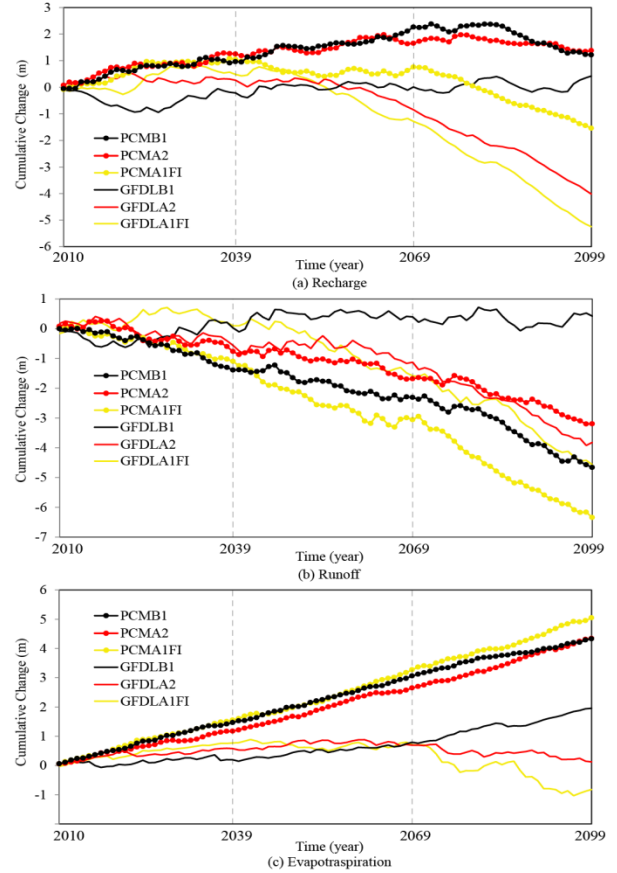
Figure 4: Cumulative changes of (a) potential groundwater recharge, (b) surface runoff, and (c) evapotranspiration with respect to the historical baseline

3. Spatial Results

Future mean annual potential recharge, runoff, and evapotranspiration with respect to the mean annual from 1950 to 2009 are listed in Table 1. The mean annual potential recharge, runoff, and evapotranspiration in 1950-2009 are 227.5 mm, 362.7 mm and 943.2 mm, respectively. The PCM model projects recharge change from −33.7 % to +19.1 % and the GFDL model projects recharge change from −58.1 % to +7.1 % for the 21st century. In general, the PCM projects more recharge than the GFDL. The potential recharge is likely to increase in 2010-2039 and is likely to decrease in 2070-2099. The mean annual potential recharge in 2070-2099 is projected to decrease from 227.5 to 95.4 mm/year under the most pessimistic scenario (GFDLA1FI), and decrease to 192.5 mm/year under the most optimistic scenario (PCMB1). As a result, the potential recharge to the Southern Hills aquifer system is projected to be reduced in 2070-2099 as the climate change studies have projected for other places (e.g., Serrat-Capdevila et al. 2007).

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Table 1: Projected changes in mean annual potential recharge, runoff and evapotranspiration with respect to the mean annual for 1950-2009.

Climate model	Scenario	Potential recharge (%) Mean annual = 227.5 mm			Runoff (%) Mean annual = 362.7 mm			Evapotranspiration (%) Mean annual = 943.2 mm		
		2010-2039	2040-2069	2070-2099	2010-2039	2040-2069	2070-2099	2010-2039	2040-2069	2070-2099
PCM	B1	+14.1	+19.1	−15.4	−12.8	−8.4	−21.6	+5.2	+5.6	+4.5
	A2	+18.4	+5.9	−4.0	−7.0	−8.4	−13.9	+4.1	+5.2	+6.0
	A1FI	+15.4	−4.2	−33.7	−10.1	−18.0	−30.2	+5.5	+6.1	+6.3
GFDL	B1	−3.1	+3.3	+6.0	+0.2	+3.4	+0.2	+0.7	+2.1	+4.1
	A2	+3.9	−16.3	−46.5	−5.1	−5.2	−24.8	+2.1	+0.4	−2.0
	A1FI	+7.1	−25.8	−58.1	+0.9	−15.5	−27.4	+2.7	−0.2	−5.4

Runoff is likely to decrease for the 21st century as projected by the GCMs (Table 1). PCM projects runoff decrease from −7.0 % to −30.2 % while GFDL projects runoff change from +3.4 % to −27.4 %. In general, PCM projects less runoff than GFDL for the 21st century. Evapotranspiration is likely to increase for the 21st century. The PCM projects evapotranspiration increase from 4.1 % to 6.3 % and the GFDL projects evapotranspiration change from −5.4 % to +4.1 %.

In order to understand the range of possible future changes in potential recharge, results from the most optimistic scenario (PCMB1) and the most pessimistic scenario (GFDLA1FI) are investigated. Figure 5 shows the changes in 30-year mean annual potential recharge with respect to the mean annual potential recharge (1950-2009). The PCMB1 projects relatively higher potential recharge increase in southeastern Louisiana than southwestern Mississippi in 2010-2039 and 2040-2069. Recharge is projected to decrease in 2070-2099. The GFDLA1FI also projects more potential recharge in southeastern Louisiana in 2010-2039. Potential recharge is projected to decrease in 2040-2069 by the GFDLA1FI and more severely in 2070-2099. In general, the PCM model projects more potential recharge than that of the GFDL model.
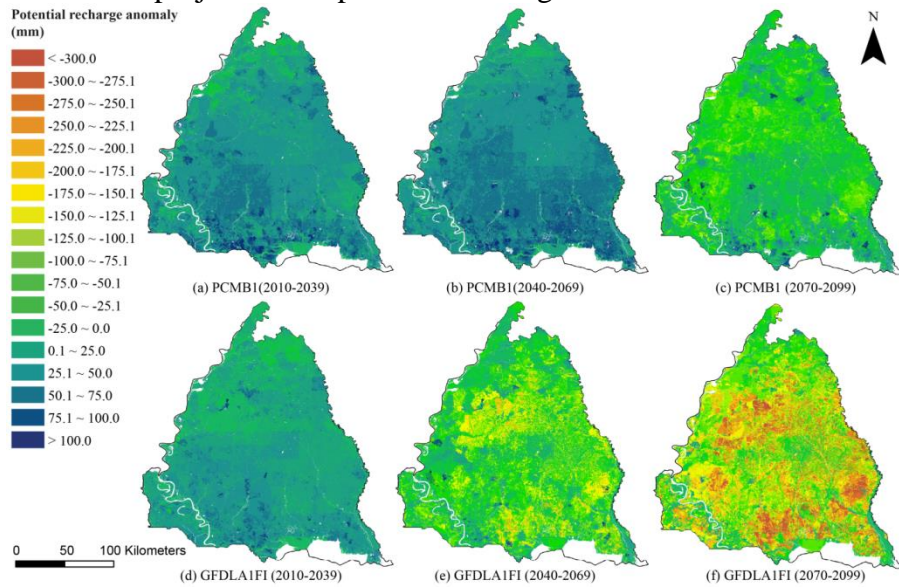

Figure 5: Potential recharge anomaly map for three future periods (2010-2039, 2040-2069, and 2070-2099) for the most optimistic scenario (PCMB1) and the most pessimistic scenario (GFDLA1FI), Each map shows the changes in 30-year mean annual potential recharge with respect to the mean annual potential recharge (1950-2009) in Figure 2.

4. Sensitivity Analyses of Recharge to Climate Change

The sensitivity of potential recharge to climate change was evaluated by using the linear regression method to analyze the relationship between the change in potential recharge and the change in individual climate variables such as precipitation, temperature and solar radiation under different climate change scenarios (Crosbie et al. 2013). The slope (dR/dP) of a linear regression represents the sensitivity of the potential recharge to a climate variable given a climate change scenario; and the intercept represents the sensitivity of the potential recharge to all other variables. A sensitivity analysis was conducted for each subdivision to assess sensitivity variation in space. This study selected GFDLA1FI scenario for the period 2070-2099 since it shows the highest potential recharge change for the study area. As shown in Figure 6, subdivisions with high potential recharge have the lowest slope and intercept while subdivisions with low potential recharge have the highest slope and intercept. As a result, subdivisions with high potential recharge show lower potential recharge sensitivity to precipitation, temperature and solar radiation and vice versa.
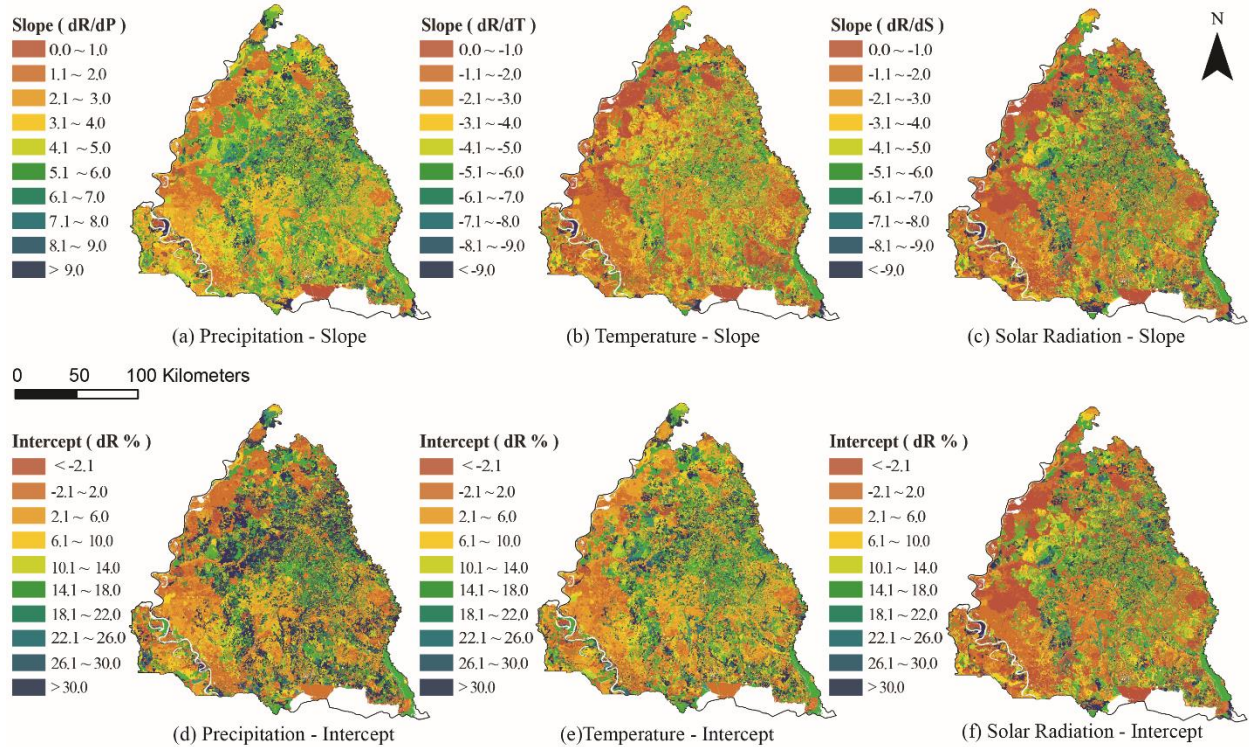
Figure 6: Slopes and intercepts of the relationship between changes in mean annual potential recharge and changes in mean annual precipitation, temperature and solar radiation for GFDLA1FI for 2070-2099.

5. Conclusions

Assessing the impact of climate change on potential groundwater recharge for humid areas can be achieved by the proposed HELP3 model in a GIS-based water budget framework. Intersecting various datasets through the GIS can easily create a great number of subdivisions, which makes the potential recharge estimation virtually infeasible on a single-core computer. The framework includes parallel programming to divide required HELP3 model runs to multiple

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cores of a supercomputer to significantly reduce computing time. The parallel programming allows the methodology to be applied to century-long potential groundwater recharge, surface runoff and evapotranspiration estimation for the area of the Southern Hills aquifer system, southwestern Mississippi and southeastern Louisiana, under a large number of emission scenarios and GCMs.

Under a wide range of climate change scenarios, it was found that the GFDL climate model projects more intense changes in future precipitation, temperature and solar radiation in the study area than the PCM model for the 21st century. Given these projected climate forcings, potential recharge is likely to increase in 2010-2039 and likely to decrease in 2070-2099 with respect to the estimated historical potential recharge (1950-2009). The study area is projected to have a wide range of future potential recharge. The potential recharge is projected to decrease in 2070-2099 by much as 58.1 % (GFDLA1FI) and to increase by as much as 19.1 % (PCMB1 scenario). Runoff is likely to decrease for the 21st century as projected by the GCMs (Table 1). PCM projects runoff decrease from -7.0 % to -30.2 % while GFDL projects runoff change from +3.4 % to -27.4 %. The PCM projects evapotranspiration increase from 4.1 % to 6.3 % and the GFDL projects evapotranspiration change from −5.4 % to +4.1 %.

It was found that the future potential recharge variation has strong correlation with the precipitation projections. Potential recharge was found to be most sensitive to the changes in future precipitation, followed by solar radiation, and then temperature. Moreover, both GCMs show a consistent result that the A1FI scenario projects the highest recharge sensitivity to the precipitation, temperature and solar radiation, followed by the A2 scenario, and then the B1 scenario. This order follows the increment of the degree of global warming in the emission scenarios. Subdivisions with high potential recharge show lower recharge sensitivity to precipitation, temperature and solar radiation.

The impact of climate change on groundwater recharge in the study area is unclear as it highly depends on selected climate models and scenarios. Using high-responsive and low-responsive climate models in conjunction with low, medium, and high emission scenarios exhibits a broad extent of uncertain future potential recharge projections. The precipitation and temperature uncertainty analyses show that precipitation influences potential recharge more than temperature.

References

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Information Transfer

Student Support

Ehsan Beigi, Doctoral Student, Department of Civil and Environmental Engineering, Louisiana State University, Baton Rouge.

Identification of Critical Nitrogen Source Areas in Lower Boeuf River Watershed

Basic Information

Title:	Identification of Critical Nitrogen Source Areas in Lower Boeuf River Watershed
Project Number:	2014LA95B
Start Date:	3/1/2014
End Date:	2/28/2015
Funding Source:	104B
Congressional District:	6th
Research Category:	Water Quality
Focus Category:	Models, Non Point Pollution, Solute Transport
Descriptors:	None
Principal Investigators:	Zhi-Qiang Deng

Publications

1. Zahraeifard, V., Z. Deng, and R. F. Malone (2015). "Modeling Spatial Variations in Dissolved Oxygen in Fine-Grained Streams under Uncertainty." Hydrological Processes, 29 (2), 212–224, DOI: 10.1002/hyp.10144.
2. Zhang, Zaihong, 2014, DEVELOPMENT OF REMOTE SENSING ASSISTED WATER QUALITY NOWCASTING AND FORECASTING MODELS FOR COASTAL BEACHES, Ph.D. Dissertation, Department of Civil & Environmental Engineering, College of Engineering, Louisiana State University, Baton Rouge, LA.
3. Deng, Z. and Zhang Z. "Bayesian Modeling and Predictions of Enterococci Levels in Gulf Coast Beach Waters." World Environmental & Water Resources Congress, May 17 – 21, 2014, Austin, Texas.

Problem and Research Objectives

Nitrogen is identified in the latest (2012) Louisiana Water Quality Inventory - Integrated Report (305(b)/303(d)) as one of the most cited suspected causes of water quality impairment. Introduction of excess river-borne nitrogen can exacerbate surface water eutrophication, favor harmful algal blooms, and aggravate oxygen depletion. This is why Dissolved Oxygen (DO) and nutrients (primarily nitrogen) are commonly listed together as the most frequently cited suspected cause of water body impairment in Louisiana. While DO and nitrogen are the most suspected cause of impairment in Louisiana, their sources are mostly unknown. In fact, the top-ranked impairment source is unknown source according to the latest Louisiana Water Quality Integrated Report. This is particularly true in agricultural watersheds, such as the Boeuf River watershed, as shown in Figure 1. As a result, the latest Louisiana Water Quality Integrated Report listed the determination of critical source areas as one of the priorities for the development and implementation of Total Maximum Daily Load (TMDL) and the restoration of water quality. This is a critical regional and state water quality problem needing to be addressed.

The overall goal of this project is to develop an efficient and effective modeling approach to identification of critical source areas (CSAs) for contaminants (including nitrogen) and thereby to address the critical regional and state water quality problem. The proposed strategy is to test and demonstrate the new modeling approach by identifying CSAs for nitrogen in the Lower Boeuf River watershed. The Lower Boeuf River (LA080901_00) is impaired due to excess nutrients and primarily nitrogen from unknown sources. The primary objective of the project is to develop a tiered new approach to the determination of catchment-scale CSAs for contaminants. The tiered approach involves (1) identification of the critical tributaries controlling nitrogen loading at the watershed scale and (2) watershed modeling for identification of the critical subwatersheds or catchments controlling nitrogen loading.
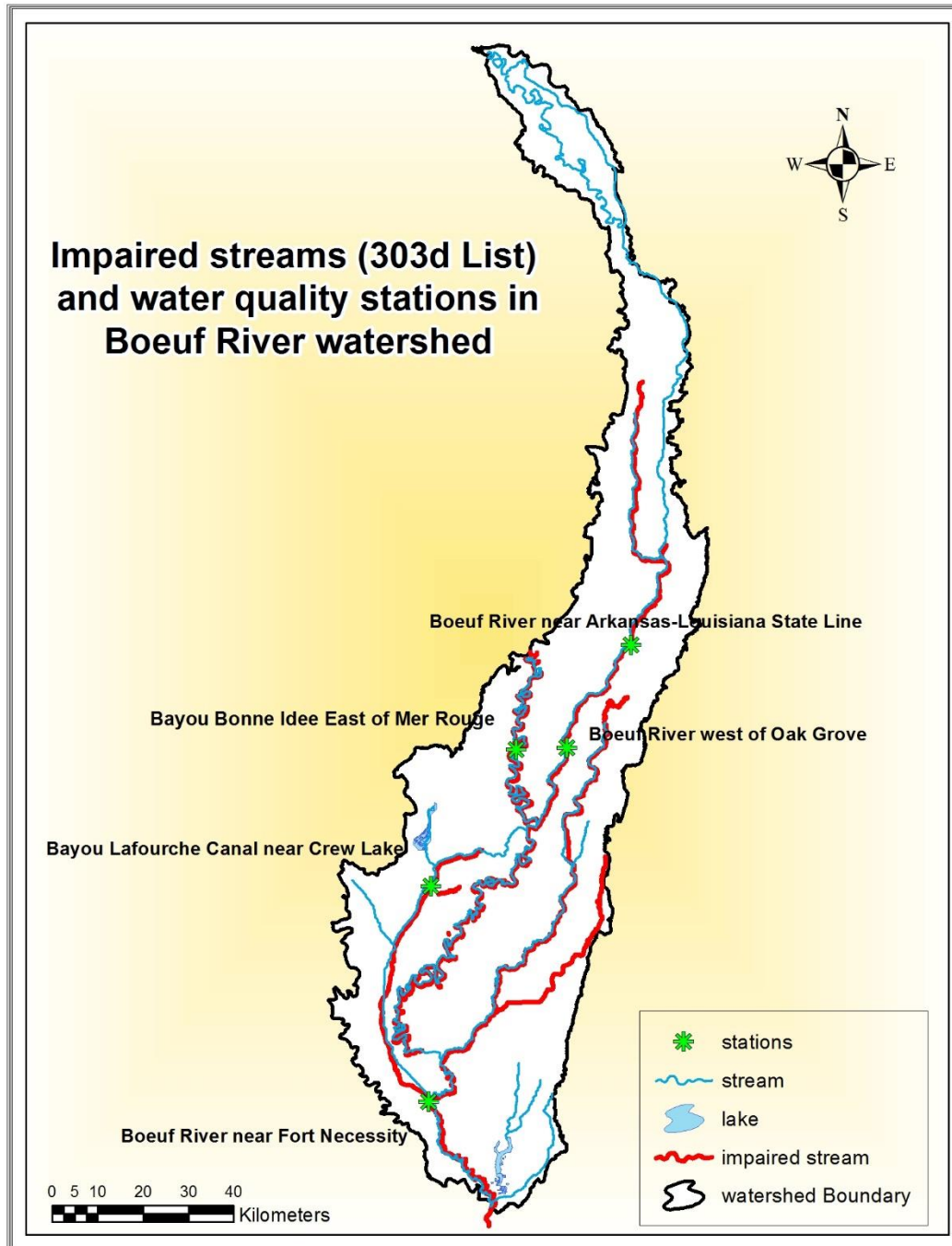
Figure 1. Study area map showing the Boeuf River watershed across the Louisiana-Arkansas border.

Methodology

The objectives are accomplished by executing three tasks: (1) watershed modeling for determining nitrogen concentrations in rivers in the watershed, (2) identification of the critical tributaries controlling nitrogen loading, and (3) mapping critical nitrogen source areas in the

watershed. The proposed tasks are implemented by combining watershed modeling tools, ArcGIS, and various data.

While this project focuses on the Lower Boeuf River Watershed, the methods developed in this study can be easily extended to other watersheds in Louisiana. Therefore, this project has broader implications for environmental restoration and sustainability in Louisiana and in the nation as well.


PRINCIPAL FINDINGS AND SIGNIFICANCE

1. Watershed modeling for determining nitrogen concentrations in rivers

(1) A HSPF-based watershed model has been presented for the Lower Boeuf River Watershed. Figures 2 and 3 below indicate that the model-simulated flow fit observed one reasonably well (correlation coefficient = 0.65). The practical significance of this model is that it provides an important modeling tool for governmental agencies like Louisiana Department of Environmental Quality to develop and implement TMDLs for the Lower Boeuf River Watershed and for restoration of impaired water bodies in the watershed.
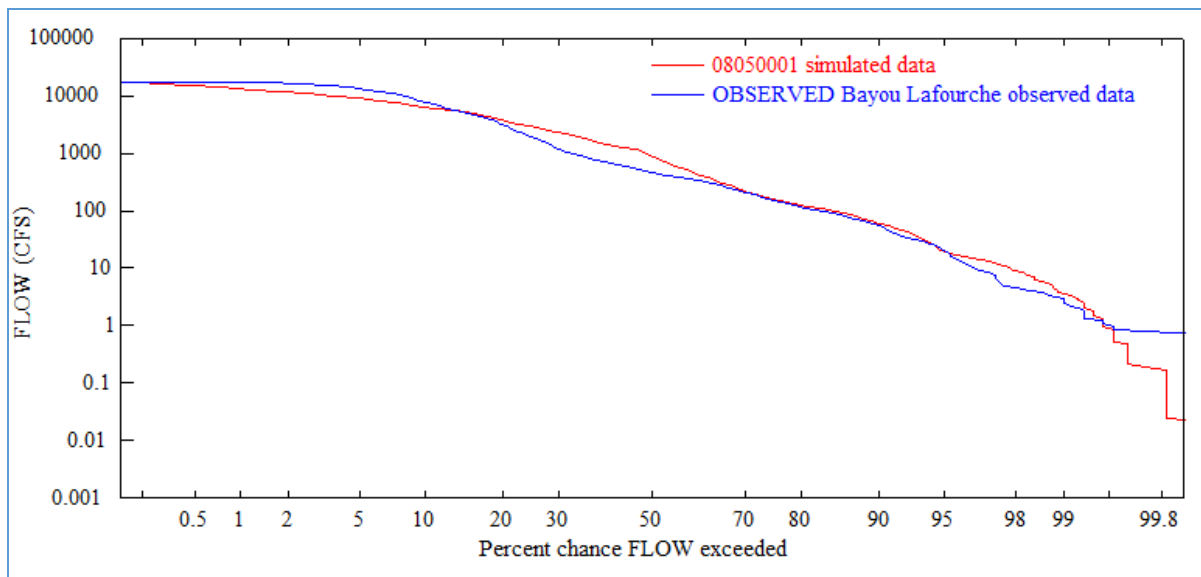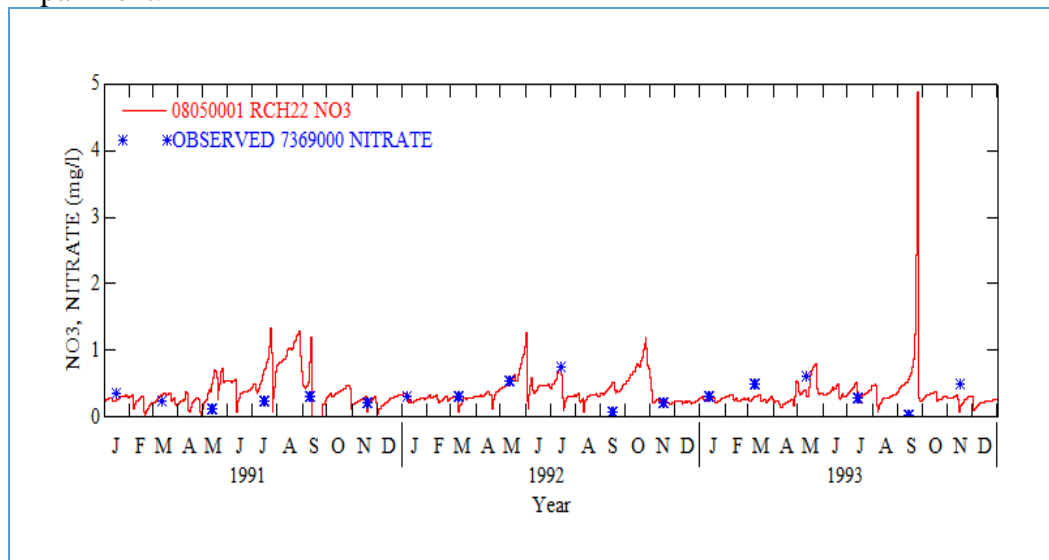

Figure 2. Comparison between simulated and observed flow of Bayou Lafourche in the Boeuf River system
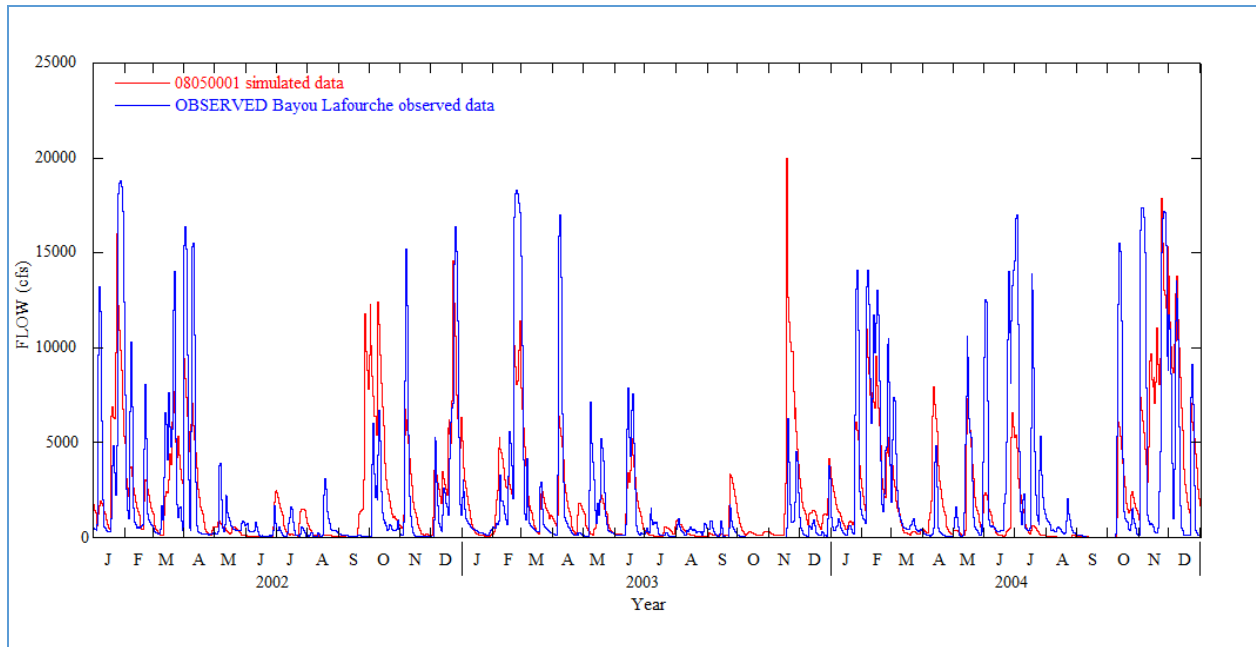
Figure 1. Comparison between simulated and observed flow of Bayou Lafourche in the Boeuf River system

(2) The HSPF-based watershed model was utilized to simulate the variation of nitrate-nitrogen concentration in the Lower Boeuf River. Figure 4 shows nitrate concentration variations in the Bayou Lafourche, a tributary of Lower Boeuf River. It can be seen from Figure 4 that the watershed model is capable of simulate nitrogen concentration in the Lower Boeuf River system. The significance of this result is that the watershed model could be employed to identify the **critical tributaries** which experienced nutrient impairment.

Figure 2. Comparison between simulated and observed nitrate concentration in the Bayou Lafourche

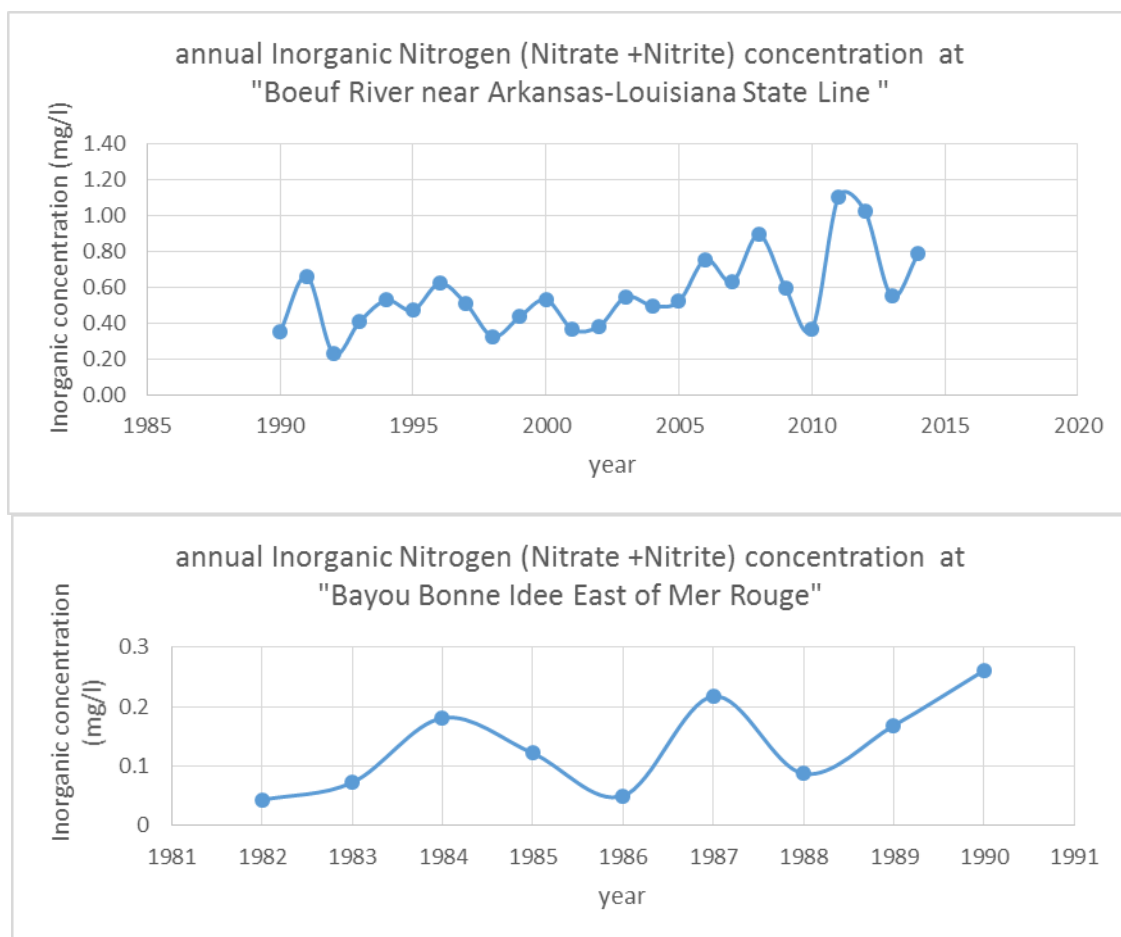**2. Identification of Critical Source Tributaries along the Boeuf River**
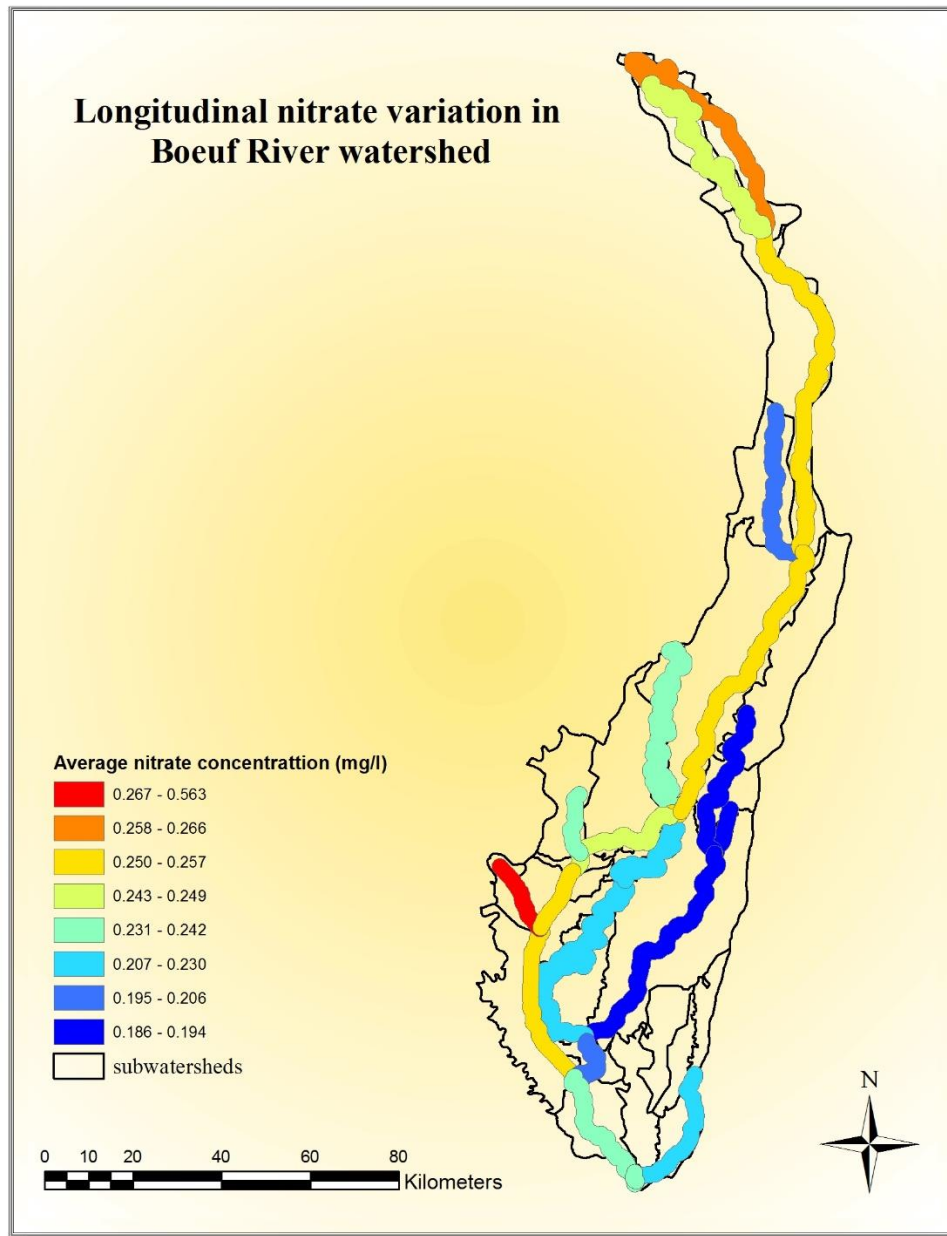
Figure 5. Map of Boeuf River watershed showing longitudinal variation in average nitrate concentration along the Boeuf River and its tributaries.

(1) Based on the simulated nitrogen concentrations, spatial variations in nitrogen concentration in rivers in the Boeuf River Watershed are mapped using ArcGIS and Google Earth to identify the critical tributaries which experienced high nitrogen concentration, as shown in Figure 5. The map indicates that elevated nitrate level in the Lower Boeuf River is primarily due to the high nitrate concentration in the Upper Boeuf

5

River in Arkansas while a small tributary (highlighted with red color) in the Lower Boeuf River Watershed is also a critical tributary to restore. It means that the Louisiana Department of Environmental Quality needs to work with the corresponding Arkansas Department of Environmental Quality in order to address the nutrient impairment problem in Louisiana rivers. This is an important finding for the Boeuf River watershed.

(2) Figure 6 shows temporal variations in nitrogen level at two sampling stations along the Boeuf River. It can be seen from the graphs that nitrogen level exhibits an increasing trend over the past decades in the watershed due to increasing agricultural activities. The significance of this result is that agricultural BMPs (Best Management Practices) should be implemented to prevent the increasing trend in nitrogen level in the watershed.

Figure 3. Temporal variations of nitrogen at three monitoring stations along the Boeuf River and its tributaries.

3. Identification of Critical Source Areas (CSAs) in the Boeuf River Watershed
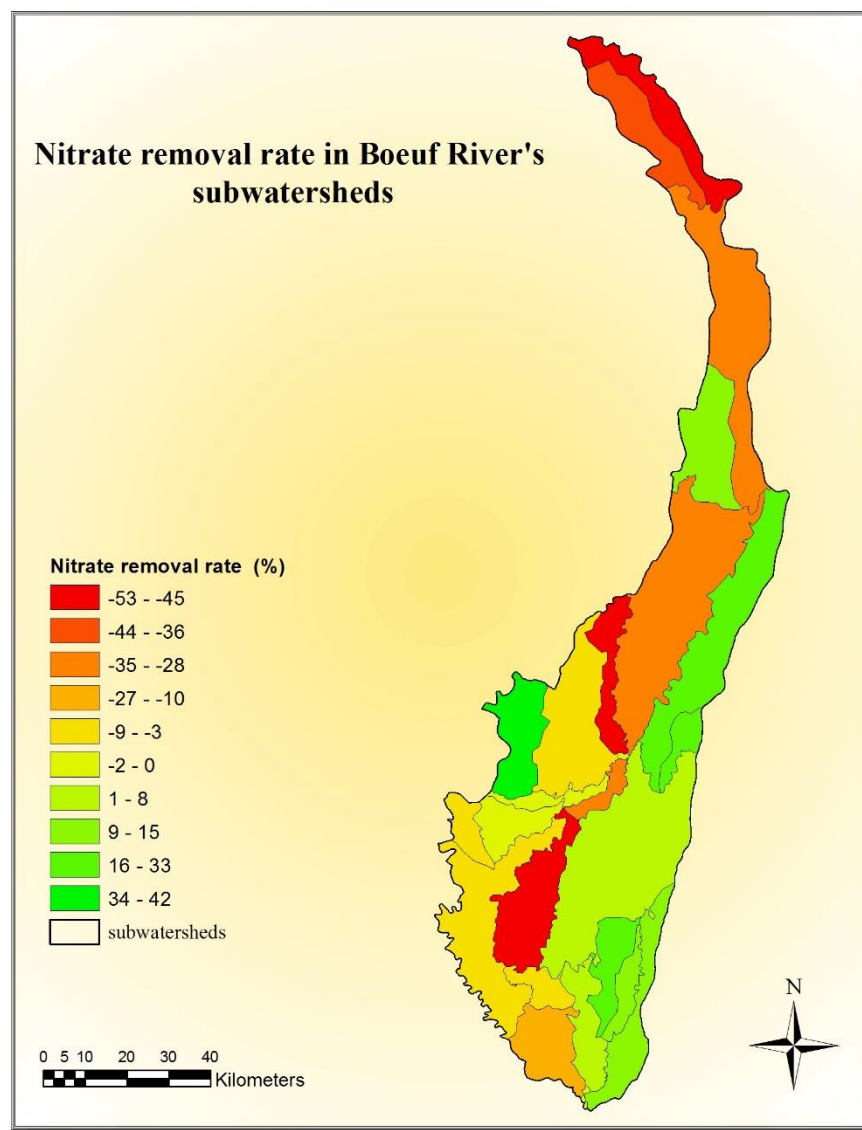
Figure 7. Map of Boeuf River watershed showing nitrate removal/release rate (%) in different subwatersheds.

The nitrate-nitrogen removal rates from all subwatersheds are mapped using simulation results from the new HSPF-based watershed model, as shown in Figure 7. ArcGIS and Google Earth are used to identify major nitrate source and sink areas in the Boeuf River watershed. The negative values show the nitrate production (release) rates, indicating nitrogen source areas, while the positive values display nitrogen sink areas. The areas highlighted with red and brown colors (particularly the red areas) are the critical sources areas of nitrogen in the Boeuf River Watershed. Again, the map demonstrates that the most critical sources areas of nitrogen are located in Arkansas while a couple of

subwatersheds in the southwest part of the watershed in Louisiana are also critical source areas. A joint and watershed-scale effort between Louisiana and Arkansas is needed to reduce nitrogen discharges to and restore water quality in water bodies in the Boeuf River Watershed. This finding is critical to both the Louisiana Department of Environmental Quality and the Arkansas Department of Environmental Quality.

INFORMATION TRANSFER

The findings and particularly the critical source areas, identified in this project, will be transferred to the Louisiana Department of Environmental Quality for nutrient TMDL development and implementation and thereby for the restoration of the nutrient-enriched or impaired Louisiana rivers.

STUDENT SUPPORT

Name of supported graduate student: Maryam Roostaee (Female)
Degree Program: Ph.D. in Water Resources
Department: LSU Department of Civil and Environmental Engineering

Effect of Herbicide Atrazine on Phytoplankton, Water Quality, and Ecosystem Functions in Louisiana Coastal Wetlands

Basic Information

Title:	Effect of Herbicide Atrazine on Phytoplankton, Water Quality, and Ecosystem Functions in Louisiana Coastal Wetlands
Project Number:	2014LA96B
Start Date:	3/1/2014
End Date:	2/28/2015
Funding Source:	104B
Congressional District:	6th
Research Category:	Water Quality
Focus Category:	Non Point Pollution, Water Quality, Toxic Substances
Descriptors:	None
Principal Investigators:	Sibel Bargu, Ronald D. DeLaune

Publication

1. Starr, Alexis Starr, 2015, Effect of Herbicide Atrazine on Phytoplankton, Water Quality, and Ecosystem Functions in Louisiana Estuaries. Master Thesis, Environmental Sciences Department, Louisiana State University, Baton Rouge, LA. (Student will graduate in summer 2015 with a master degree from Environmental Sciences Department, Louisiana State University.)

Problem and Research Objectives

In the United States, approximately 857 million lbs of conventional pesticide active ingredient were applied in 2007 and 80% of US pesticide use during this time was in agriculture (USEPA, 2011). There are several types of pesticides, including insecticides, rodenticides, herbicides, and fungicides, named for their target organisms. While pesticides have many beneficial uses, they can also adversely affect the environment. Pesticides can be transported to non-targeted areas through surface runoff, leaching, erosion, and through other mechanisms (Larramendy and Soloeski, 2014). Watersheds that contain a high proportion of agricultural land use are especially susceptible to pesticide contamination due to runoff (LDEQ, 1998). As a result, Louisiana's estuaries may be vulnerable to elevated pesticides levels, such as the herbicide atrazine. Atrazine is used both pre-emergence and post-emergence to control annual broadleaf and grass weeds in corn, sugarcane, and sorghum production (Solomon et al., 1995). Atrazine is used extensively in the Midwest for corn production and as a result, may enter the Mississippi River through runoff. The River then carries the chemical down stream where it is discharged into Louisiana's estuaries and eventually into the Gulf of Mexico. Atrazine may also indirectly enter Louisiana estuaries as a result of the sugarcane industry located in the south eastern part of the state through surface runoff brought on by rainfall and storm events. Elevated atrazine levels may negatively impact local estuarine organisms, specifically, phytoplankton since atrazine is known to inhibit photosynthesis. The phytoplankton response to atrazine exposure at various concentrations can be especially important to higher trophic levels since their growth and abundance can determine the potential productivity of the entire ecosystem (Wissel and Fry, 2005).

The purpose of this study was to determine the extent of atrazine present in Louisiana estuaries due to agricultural runoff under different flow and nutrient regimes (Spring and Summer) and its effect on the growth response and oxygen production of the local phytoplankton community.

Principal Findings and Significance

Methodology:

Atrazine levels were measured in Breton Sound Estuary for the months of May, June, and August and in Barataria Estuary during June and August. The three points within each estuary were sampled at varying distances from the closest river diversion. Chlorophyll a, nutrients and environmental conditions were examined together with atrazine levels. Local phytoplankton were also collected from Barataria Estuary and grown in microcosm and exposed to an atrazine dilution series. The dilution series was designed to mimic peak atrazine levels that have occurred in many tributaries, lakes, and other water bodies throughout the United States during the spring.

Field Atrazine Analysis:

Water samples were collected in 2 liter Nalgene bottles and transported to the laboratory on ice. Water samples designated for atrazine analysis were stored in a refrigerator at 4 °C overnight, and analyzed the following morning. Atrazine was extracted from the water samples using liquid-liquid portioning with Methlylene Chloride (Dichloromethane) and exchanged to Hexane. The extract was concentrated to 1 ml using an N-EVAP. An Agilent 7683 Automated liquid sampler was used to inject 2µl of 500 ml/ml extract into a Hewlett Packard 6890 Gas Chromatograph (GC) with an RTX 5MS 30 M x 0.25 mm x 0.25 µm capillary column installed.

Helium, used as a carrier gas, flowed throw a split-less mode inlet at 1.0 ml/min and 1 °C. The oven temperature was set to 80 °C with a hold time of 2 minutes, was set to increase 30 °C/min until a temperature of 190 °C was reached. After the oven reached 190 °C, it was set to increase 8 °C/min until the temperature of 300 °C was reached. Once the oven reached 300 °C, it was held at that temperature for 5 minutes.

The flow then continued through a 280 °C transfer line to a Hewlett Packard 5973 Mass Selective Detector in Selective Ion Monitoring mode, with a source temperature of 230 °C and a quadruple temperature of 150 °C. The ions (m/z) monitored for atrazine were 172.95, 200.05, 211.05, 215.05, and the retention time was 9.13 minutes. Single point external quantitation was performed using the 215.05 ion (m/z) with 200.05 and 172.95 as qualifiers at 35% and 172%, respectively, against an analytical standard of 0.20pm. A second injection of all samples, using the same initial GC parameters, but a different detection mode, allowed for a full scan confirmation of positive atrazine samples. This was done using a Hewlett Packard MSD that monitors ions between 50-450.

Experimental Setup for Laboratory Growth Experiments:

Samples were initially divided into two groups, with (+) and without (-) nutrient enrichments (Fig. 1). Nutrients were initially added to the enriched treatment group according to the ratios outlined in DY-V media instructions. Each group was then further divided by atrazine treatments. Each sample contained the same volume of non-enriched filtered estuarine water ((-) FEW) or enriched filtered estuarine water ((+) FEW) solution to ensure the initial concentration of phytoplankton was approximately the same for all flasks at the start of the experiment. The growth experiment atrazine treatment groups consisted of 5 ppb, 50 ppb, and 200 ppb atrazine,

while the oxygen production experiment atrazine treatment groups consisted of 10 ppb and 100 ppb atrazine. For each experiment, two control groups containing only phytoplankton with no atrazine addition in the nutrient enriched and non-enriched groups were used. Sterilized Pyrex flasks were used in the growth experiment. For the Oxygen production experiment, sterilized glass bottles (300 ml) with glass penny head stoppers were used. The test media volume was 300 ml to ensure no air remained in the bottles. All experimental flasks and bottles were kept at 24 °C on a 12:12 h light:dark cycle with cool white fluorescent lights at an irradiance of 85 $\mu E\ m^{-1}s^{-1}$ for a period of 10 days.

For the growth experiment, 10 ml water subsamples were taken from each flask over a 10-day period to determine daily changes in phytoplankton biomass. Each subsample was filtered through a 25 mm GF/F filter and stored in the freezer at -20 °C until extraction. The filters were then extracted for 24 h in 90% aqueous acetone at -20 °C and subsequently analyzed for Chl *a* using a Turner fluorometer (Model 10-AU) (Parsons et al., 1984). For oxygen production experiment, the dissolved O_2 concentrations were measured every other day using a Clark-type microelectrode sensor with a 100μm tip. The oxygen sensor chosen for this particular application has a response time <8 sec, a stirring sensitive of <0.5%, a detection limit of 0.05 μM and a negligible analyte consumption rate of $5-50x10^{-4}$ nmol hr^{-1}.

Results and Discussion:

Atrazine was consistently measured in Breton Sound and Barataria Estuaries over the months sampled (Table 1 and 2). However, these levels were found to be significantly below the maximum contaminant level of 3 ppb set by EPA (USEPA, 2002) and the lowest atrazine treatments of 5 and 10 ppb used in the growth and oxygen production experiments. Acute

atrazine levels in surface waters tend to peak in March and April due to the time of application and increased rainfall. The field samples used on this study were collected later in the year during May, June, and August of 2014. This suggests that the atrazine levels measured in this study were not indicative of peak concentrations as there was more time for the chemical to become diluted, degrade, adsorb, and be taken up by aquatic organisms. As a result, the Louisiana phytoplankton may be exposed to higher atrazine levels in March and April than the months sampled, which may potentially impact the phytoplankton community and the ecosystem as a whole during that time. Field samples were taken in large water bodies where atrazine could become easily diluted. Louisiana streams and tributaries have consistently exhibited atrazine levels higher than EPA's maximum contaminant level (USEPA, 2002). As a result, phytoplankton communities located in these smaller water bodies may be more susceptible to the chemical as it is less likely to become diluted. Based on the low atrazine concentration and high nutrient availability in both Breton Sound and Barataria Estuaries, it is likely that the native phytoplankton community would be able to recover from acute atrazine exposure at levels found in field samples.

Table 1: Depicts distance to the Caernarvon Diversion and atrazine concentrations measured in Breton Sound Estuary during May, June, and August of 2014. Values measured below the detection limit are denoted as "bdl".

Month	Station	Distance to Diversion (km)	Atrazine(ppb)
	Caernarvon Outfall	2.5	0.42
May	Big Mar	4.5	bdl
	Lake Lery	8	bdl
	Caernarvon Outfall	2.5	0.37
June	Big Mar	4.5	0.4
	Lake Lery	8	0.16
	Caernarvon Outfall	2.5	0.34
August	Big Mar	4.5	0.22
	Lake Lery	8	0.55

Table 2: Depicts distance to the Davis Pond Diversion and atrazine concentrations measure in Barataria Basin during June and August of 2014.

Month	Station	Distance to Diversion (km)	Atrazine(ppb)
June	Upper Lake Cataouatche	10.8	0.1
	Lake Cataouatche	14.6	0.24
	Lake Salvadore	22.6	0.2
August	Upper Lake Cataouatche	10.8	0.23
	Lake Cataouatche	14.6	0.24
	Lake Salvadore	22.6	0.24

The results of the growth response and oxygen production experiments indicate that Louisiana phytoplankton could overcome low (5 ppb) and medium (50 ppb) atrazine exposure in high nutrient conditions (Figure 1,3). Under these treatments, the community experienced an extended lag phase, and entered the exponential phase several days after the control groups. The communities grown under high nutrient conditions grew more rapidly and produced higher levels of oxygen over the 10-day period than the low nutrient treatment groups (Figure 1, 2, 3, and 4). There was a greater stress response in the non-enriched treatment group brought on by the combined effect of atrazine exposure and a lack of sufficient nutrients.

As a result, these low acute levels present in the estuaries may only slightly delay phytoplankton blooms. However, due to the persistence of atrazine in the environment, it is likely that aquatic organisms are susceptible to chronic atrazine exposure in these estuaries. Chronic atrazine exposure at low levels may have a different effect than acute influxes on the phytoplankton community. Because phytoplankton are so sensitive to environmental factors, it is likely that the chronic presence of atrazine, even at low levels, may impact the community composition, as the phytoplankton are unable to properly acclimate. Over time, species may become more tolerant to atrazine due to chronic exposure. This may increase the chance of

transferring the contaminant to higher trophic levels under acute exposure conditions. The native community may also experience a long-term shift from more sensitive species, such as chlorophytes, to more resilient species, such as diatoms. This shift in composition has the potential to reduce species richness, alter food web dynamics, nutrient cycling, and energy flow between trophic levels.

As a result, further study should be conducted on field atrazine levels in Breton Sound and Barataria Estuaries as well as the response to Louisiana native phytoplankton to chronic atrazine exposure. Native phytoplankton communities should be used in further experimentation to determine the growth response, oxygen production, and extent of any community composition shifts associated with chronic atrazine exposure. Atrazine levels should also be monitored year round in these estuaries to determine the timing of peak acute exposure in estuarine systems and persistence in the environment to determine the extent of exposure in these systems.
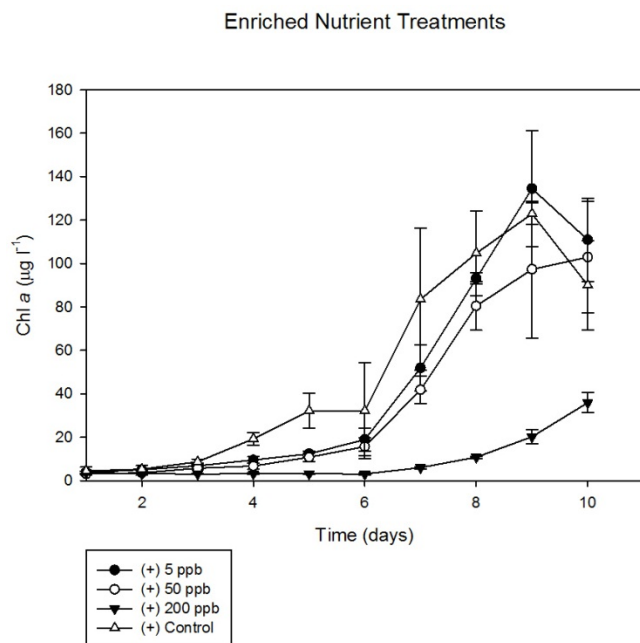

Figure 1: The chlorophyll a ($\mu g\ l^{-1}$) concentrations of the nutrient enriched (+) and control group (n = 3) with (+) 5 ppb, (+) 50 ppb, and (+) 200 ppb of atrazine.
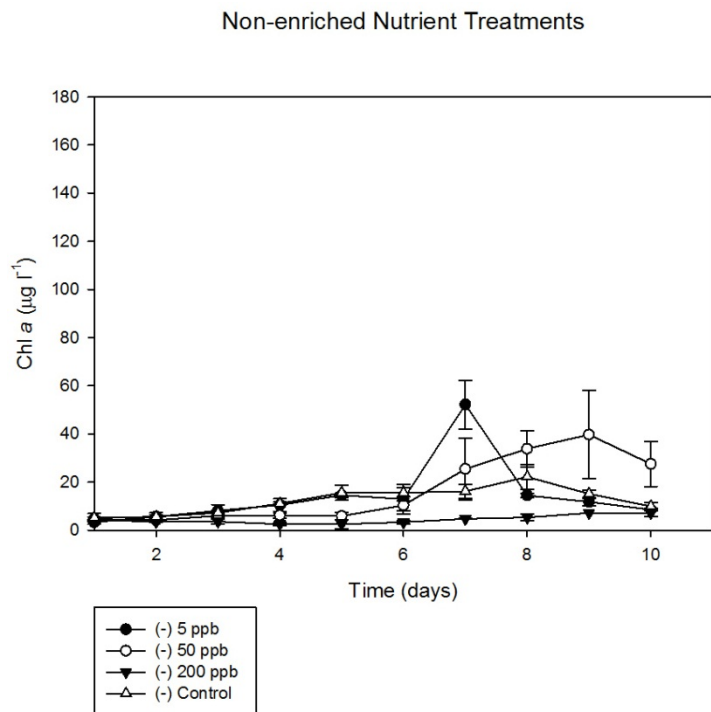
Figure 3: The chlorophyll *a* (Chl *a*, μg l^{-1}) concentration of the non-enriched (-) control group and replicates treated with 5 ppb, 50 ppb, and 200 ppb of atrazine. The measurements were taken over a ten-day period.
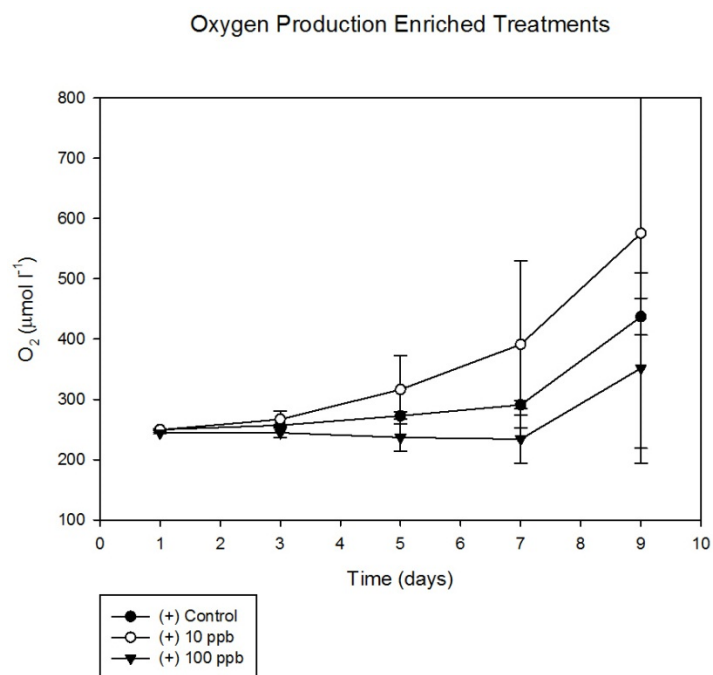
Figure 3: The oxygen production (μmol l^{-1}) of enriched (+) replicates. Sample treatments were designated as control with no atrazine addition, 10 ppb, and 100 ppb atrazine. Oxygen levels were recorded every other day over a ten day period.

Oxygen Production Non-enriched Treatments
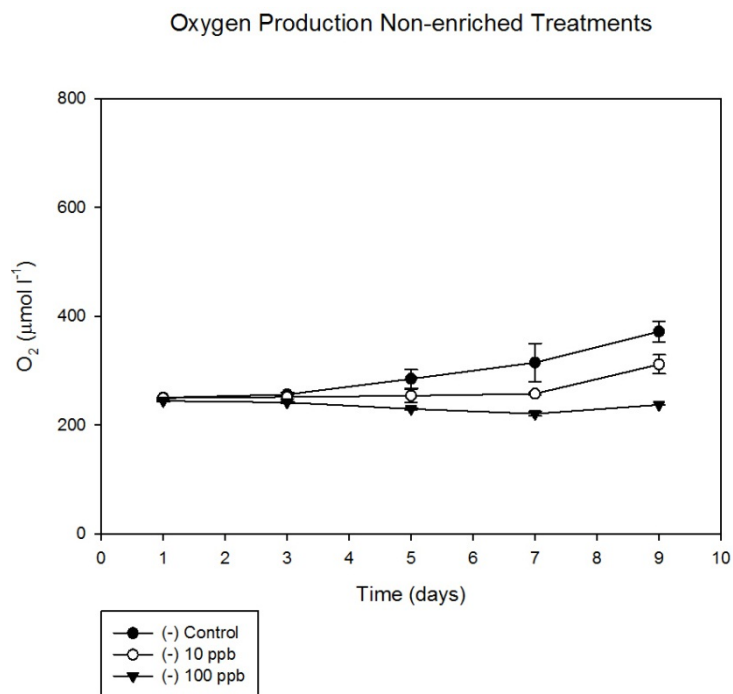
Figure 4: The oxygen production (μmol l$^{-1)}$ of non-enriched (-) replicates. Sample treatments were designated as no (control), 10 ppb, and 100 ppb atrazine. Oxygen levels were recorded every other day over a ten-day period.

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Parsons, T.R., Y. Maita, C.M. Lalli. 1984. A manual of chemical and biological methods for seawater analysis. 173:285-295.

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U.S. Environmental Protection Agency. 2002. Summary of atrazine in EPA Region 6 surface waters. U.S. Environmental Protection Agency Region 6. Dallas, TX.
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Wissel, B. and B. Fry. 2005. Tracing Mississippi River influences in estuarine food webs of coastal Louisiana. Oecologia 144: 659-672.

Student Support
$3.300 support Alexis Starr summer hours

Adaptive management of Catahoula Lake for Sediment Mobility and Control of Woody Encroachment

Basic Information

|	
Title:	Adaptive management of Catahoula Lake for Sediment Mobility and Control of Woody Encroachment
Project Number:	2014LA97B
Start Date:	3/1/2014
End Date:	2/28/2015
Funding Source:	104B
Congressional District:	6th
Research Category:	Climate and Hydrologic Processes
Focus Category:	Wetlands, Sediments, Hydrology
Descriptors:	None
Principal Investigators:	Richard Keim, Brandon Edwards

Publications

1. Dugué, Lincoln. 2015. Hydrological influence on Catahoula Lake in an Altered Floodplain. MS Thesis, School of Renewable Natural Resources, Louisiana State University, Baton Rouge, LA
2. Edwards, B.L., M. Curcic, and R.F. Keim. 2014. Modeling wave effects on limits of woody vegetation in Catahoula Lake, LA, USA. Abstract presented at 2014 Fall Meeting, American Geophysical Union, San Francisco.
3. Keim, R.F., K. Latuso, R.D. DeLaune, and D.C. Weindorf. 2014. Sediment deposition into a valley-margin lake in a managed floodplain, Catahoula Lake, Louisiana, USA. Abstract presented at 2014 Fall Meeting, American Geophysical Union, San Francisco.

Problem and Research Objectives

Hydrologic management of wetlands and lakes often creates consequences for local ecosystems. Small changes in flooding and drought cycles can create large changes in plant communities and ecosystem structure. Because there are fewer and fewer wetlands remaining with natural hydrologic variability, and because wetland ecosystem services are becoming more valued, it becomes increasingly important to develop hydrologic management strategies to target desired conditions. However, in many cases it is unclear what management strategies are most appropriate and adaptive management of water for ecosystem structure is necessary. One of the most important examples of this problem in Louisiana is at Catahoula Lake (Figure 1), which is a critical, high-value managed wetland currently undergoing undesired ecosystem change.

Catahoula Lake is an important wetland for wildlife habitat in the Lower Mississippi Alluvial Valley (LMAV) characterized by highly variable water levels. Its proximity to the floodplain margin has prevented rapid sedimentation from the Mississippi or Red rivers leading to development of a perirheic wetland lake (Mertes 1997), rather than a forested floodplain. The lake bed consists of a broad, seasonally inundated herbaceous flat bordered by a band of woody shrubs—water-elm (Planera aquatica) and, to a lesser extent, swamp-privet (Forestiera acuminata)—which transitions to baldcypress and bottomland hardwoods with elevation.

Hydrologic variability is driven by both local runoff and the Mississippi River system. The resulting annual summer de-watering of the lake allows the lake bed to support a moist-soil vegetation community of high value for migratory waterfowl (Wills 1965), but encroachment by woody shrubs over the past ~70 years threatens ecosystem conversion to forest. Catahoula Lake has been internationally recognized under the Convention on Wetlands of International Importance (the Ramsar Convention) since 1991, and the control of woody encroachment is a high priority for the Louisiana Department of Wildlife and Fisheries (LDWF) and the U.S. Fish and Wildlife Service (FWS).
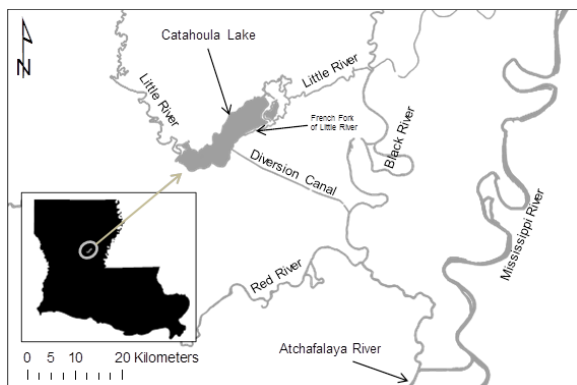

Figure 1. *Location map and hydrologic setting of Catahoula Lake, LA*

Hydrological processes controlling Catahoula Lake water levels and sedimentation have been progressively altered by navigation projects, water control structures, and subsequent geomorphic adjustments in the Mississippi and Red rivers (Latuso 2014, Dugué 2015).

The hydrological conditions in Catahoula Lake are most closely related to the Black River. Construction of locks and dams on the Black River began in 1926. In 1972 a new, higher set of locks and dams were completed on the Black and Little rivers near Catahoula Lake (Saucier 1998). To prevent permanent deep flooding and attempt to preserve the hydrological regime of the lake, the Catahoula Diversion Channel was constructed from the lake to the Black River below the lowest lock, and a control structure installed to partially control drainage from the lake (Figure 1). This channel was intentionally constructed to allow greater flow than the French Fork of the Little River, which was the original outlet of the lake but was closed in 1972 (USACE 1963, as cited by Bruser 1995).

The management plan for the Catahoula Diversion Channel since its completion has been to mimic the hydrological regime prior to the Ouachita-Black Navigation Project. Although there have been some variations through time, the general plan has been to keep the lake flooded from November-January at about 29.5 feet, increase stage to about 34 feet until July, and to de-water the lake to the 27-foot minimum July 1-November. However, targets are not always met because of both local and large-scale climate variations.

In recent decades there has been encroachment of woody shrubs into Catahoula Lake (Figure 2). Woody shrub cover decreases or eliminates production of the herbaceous community (Brown 1943, Wills 1965, Weller 1989), which reduces food value for waterfowl. Therefore, the Louisiana Department of Wildlife and Fisheries has periodically removed woody shrubs in an effort to maintain high quality waterfowl habitat. Encroachment has been occurring since at least the 1950s, but Wills (1965) described the rate of re-colonization as "very slow." The rate of encroachment has apparently increased since then (Bruser 1995), and Wills and Davis (1977) describe aggressive mechanical removals of water-elm and swamp-privet that occupied 10,000 acres by that time. LDWF is now routinely pursuing woody plant control efforts annually.

a) 1940   b) 2007

0 1 2   4   6
                Km   N
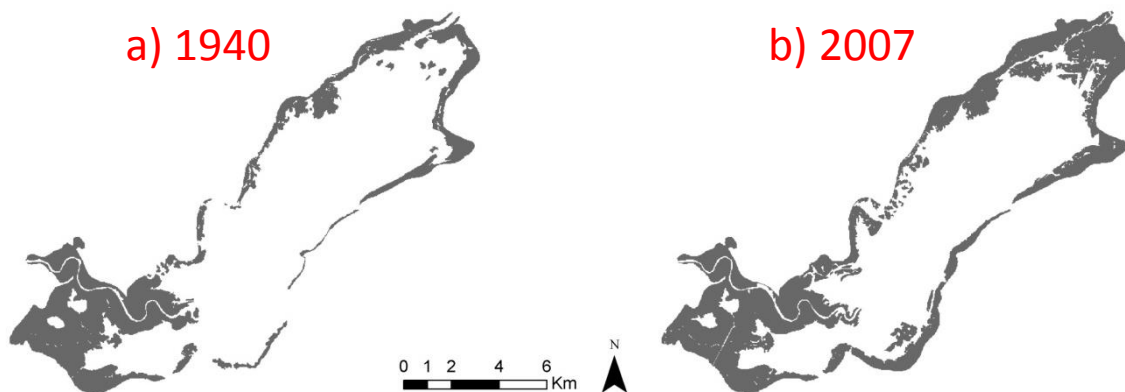
Figure 2. *Woody encroachment at Catahoula Lake. Perimeter of high density woody shrubs for a) 1940 and b) 2007. This encroachment threatens valuable waterfowl habitat and control of continuing encroachment is a management priority. Encroachment is highest on the northeastern end of the lake and relatively low around the rim of the main lake.*

Despite management intentions, there are strong indications that the management of the lake has been responsible for vegetation changes. Premature de-watering relative to the pre-existing natural regime has been linked to observed woody germination events. Bruser (1995) found that operation of the Catahoula Diversion Channel increased drainage rates of lake above those prior to its construction, that they decreased water level variations from August to November, and predicted that these changes would eventually lead to a conversion of the lake to a shrub swamp. Willis (2009) found that baldcypress growing on the western fringe of Catahoula Lake experienced a step increase in growth rates coinciding with the 1972 opening of the Catahoula Diversion Channel, which suggests more hydrologic stable conditions during the growing season. Although the specific details of processes controlling vegetation change are not clear, it is apparent that woody vegetation is now more favored than it was prior to the Diversion Channel, and that the management plan does not mimic the hydrologic regime under which the desired vegetation communities developed.

A new approach is needed for managing water in Catahoula Lake to counteract changes in ecosystem structure. Our goal is to provide decision makers with an adaptive water level management strategy designed to control woody encroachment on the lake bed. Sediment mobility and stresses resulting from wave action prevent establishment of seedlings through disturbance of the soil substrate and uprooting, and we propose that similar processes can be managed adaptively to control encroachment in Catahoula Lake. To accomplish this goal, we developed a stochastic model of hydrodynamic conditions conducive to sediment bed mobility and stress for a range of possible environmental and hydrologic conditions, so that lake water levels can be managed to increase bed disturbance.

Methodology

Historical water level analysis
Historical water levels for Catahoula Lake were analyzed for pre- and post-canal conditions. Lake levels were taken from the center-of-lake gage managed by the USACE for post-canal water level conditions (USACE 2014), and from the Placid Oil gage (private) for pre-canal water conditions.

Wind analysis
Wind data were analyzed using a joint probability distribution calculated using wind speed and direction data from the nearby Esler Regional Airport station for 1/1/1994-12/31/2013 (NCDC 2014).

An angular-linear joint probability function, $f_{V,\Theta}(v,\theta)$, can be defined by (Johnson and Wehrly 1978):

$$f_{V,\Theta}(v,\theta) = 2\pi g(\zeta)f_V(v)f_\Theta(\theta); \;\; 0 \leq \theta < 2\pi, -inf \leq v < inf$$

Where $f_V(v)$ and $f_\Theta(\theta)$ are the probability density functions of wind speed and direction, respectively, and $g(\cdot)$ is the probability density function of ζ, a circular variable defined by:

$$\zeta = 2\pi[F_V(v) - F_\Theta(\theta)]$$

where $F_V(v)$ and $F_\Theta(\theta)$ are the cumulative distribution functions of wind speed and direction, respectively.

Marginal distributions for wind speed and direction can be defined by a mixed singly truncated from below normal Weibull distribution for speed and a mixture of von Mises distributions for direction (Carta et al. 2008). This approach accounts for correlation between speed and direction, includes the frequency of zero-wind events, adequately describes unimodal or bimodal speed regimes, and can represent multiple prevailing wind directions (Carta et al. 2008).

Wave modeling

We used the University of Miami Wave Model (UMWM, Donelan et al., 2012) to estimate hydrodynamic conditions in the lake. The model solves the evolution of wave energy balance equation through time:

$$\frac{\partial E'}{\partial t} = \rho_w g \sum_{i=1}^{N} S_i$$

where E' is wave energy spectrum, ρ_w is the water density and g is gravitational acceleration. The source terms, S_i consist of wave growth (S_{in}), wave dissipation (S_{ds}), non-linear wave-wave interactions (S_{nl}), and bottom friction and percolation (S_{bf}) (Donelan et al. 2012).

The UMWM model resolves the following physical processes: (1) wave growth by wind; (2) wave dissipation by (a) spilling (deep water), (b) plunging (shallow water), (c) turbulence in the wave boundary layer, (d) bottom friction, (e) bottom percolation, and (f) viscosity; (3) modulation of short waves by long waves; (4) downshifting of energy due to non-linear dissipation and wave-wave interactions; (5) propagation of waves; (6) advection of wave energy by ocean currents; and (7) bottom and current-induced wave refraction.

The model requires inputs of bathymetry and meteorological forcing. We estimated bathymetry based on available data (Figure 3, Michot et al. 2002, USGS 2014). We truncated the developed elevation estimates by the 1940 tree line to model the effects of water management on woody encroachment in the lake bed.

We used multiple iterations of steady state wind conditions, e.g. a steady velocity from a single direction, to model potential wind scenarios for water level conditions ranging from 34 to 40 ft depth at the center of the lake. Output from model scenarios was used to assess the potential impacts of hydrologic management on bottom shear stress and bed mobility due to wave action in the lake.
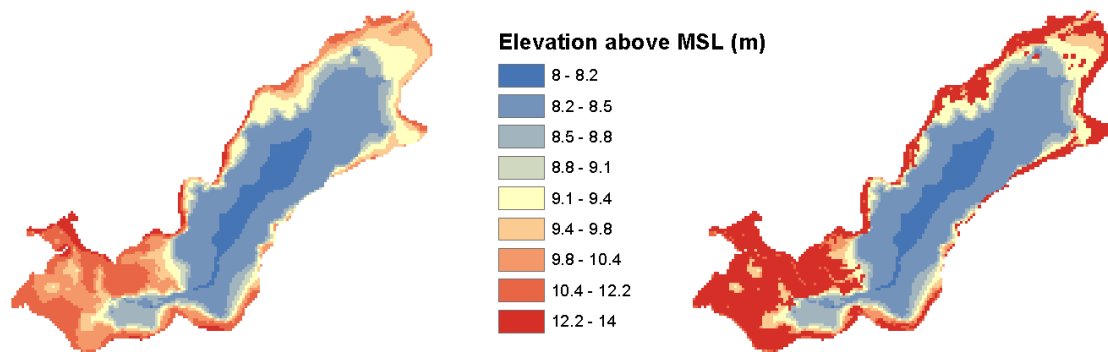
Figure 3. *Model bathymetry for Catahoula Lake. A) Bathymetry for the lake basin estimated from USGS NED DEM data and Michot et al. (2002), and b) bathymetry truncated by 1940 high density shrub perimeter. The high density tree line was treated as the model boundary.*

Principal Findings and Significance

Historic water levels were reconstructed for the center of Catahoula Lake. Overall, hydrologic variability has been moderated and extreme flood events have decreased due to hydrologic management (Figure 4). Notably, much of the natural variability in the timing of late spring and early summer months has been lost due to managed drawdowns via the diversion canal (Figure 4). Prior to hydrologic control via the diversion canal control structure, there was a much greater likelihood of maintaining flooded conditions into the early summer months (Figures 4, 5).

Stochastic analysis of wind data for the region indicates that the strongest winds are predominantly southerly during the late spring and shift toward southwesterly in the early summer, particularly in July (Figure 6). These winds combined with relatively shallow water levels are favorable for causing the maximum wave stress in the northeastern end of the lake, where woody encroachment has been greatest (Figure 2). Results from wave modeling indicate that there are sufficient wind events, in terms of both speed and direction, during this period to cause bottom shear stress to exceed entrainment and bed mobility thresholds for much of the lake (Figure 7). Further, seedling uprooting thresholds (Schutten et al. 2005, Balke et al. 2011, 2013) suggested by the literature are reached under rare conditions, e.g. 8 m/s and higher winds sustained for 1 hour or more).

Even during this period, when winds and historic water levels are best suited for bed disturbance due to waves, the probability of events sufficient to uproot woody seedlings is small. Likely, uprooting events historically occurred on a multi-annual scale. Perhaps more important were annual, moderate events that were more likely to occur during slower, more natural lake ebbs or prolonged floods. Under current hydrological management, however, the likelihood of either is essentially nil.

These results suggest that hydrologic management, particularly managed drawdowns at the end of spring, have removed natural hydrologic variability from the lake. Thus, during the time

period that historically has been potentially the most conducive to large bottom shear stresses, bed mobility, and seedling uprooting, water levels in the lake are too low for wave action to play a part in shaping the ecological structure of the lake bed--specifically in the northeastern end of the lake, where elevation is slightly higher and woody encroachment has been the most significant (Figure 8).

There are several water management scenarios that could contribute to controlling woody establishment, but the most effective may be to introduce hydrologic variability into the late spring-early summer hydrograph by managing water levels to fluctuate at low to moderate levels. This could allow for periods of germination and subsequent removal of woody seedlings while mimicking more natural, pre-control variability. Under such a scenario, adverse effects on desired herbaceous communities which grow during the late summer-early fall would be minimized.

Under current management, there is less potential for wave induced stress on the lake bed than prior to hydrologic control, particularly in the early summer. More research is needed to develop specific water level management strategies to maximize the potential for bed mobility and wave stress. Further, species-specific uprooting thresholds need to be measured to better understand ecogeomorphic feedbacks.
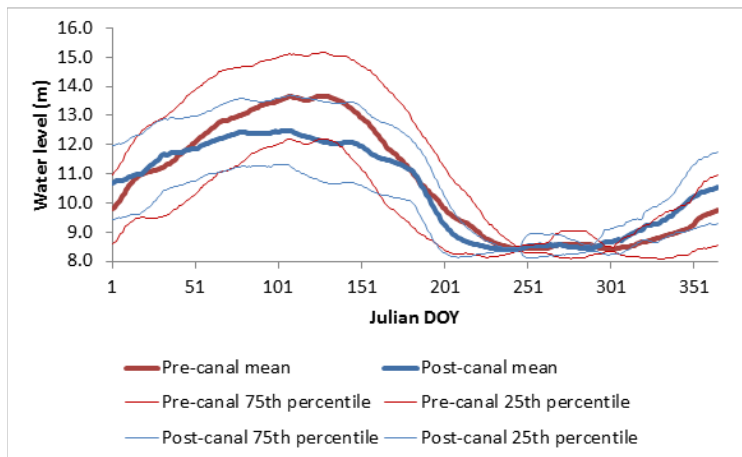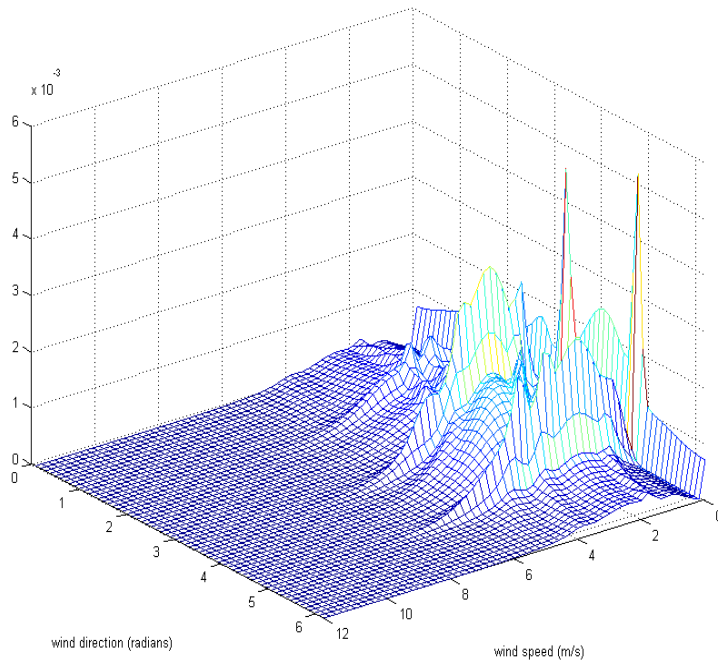

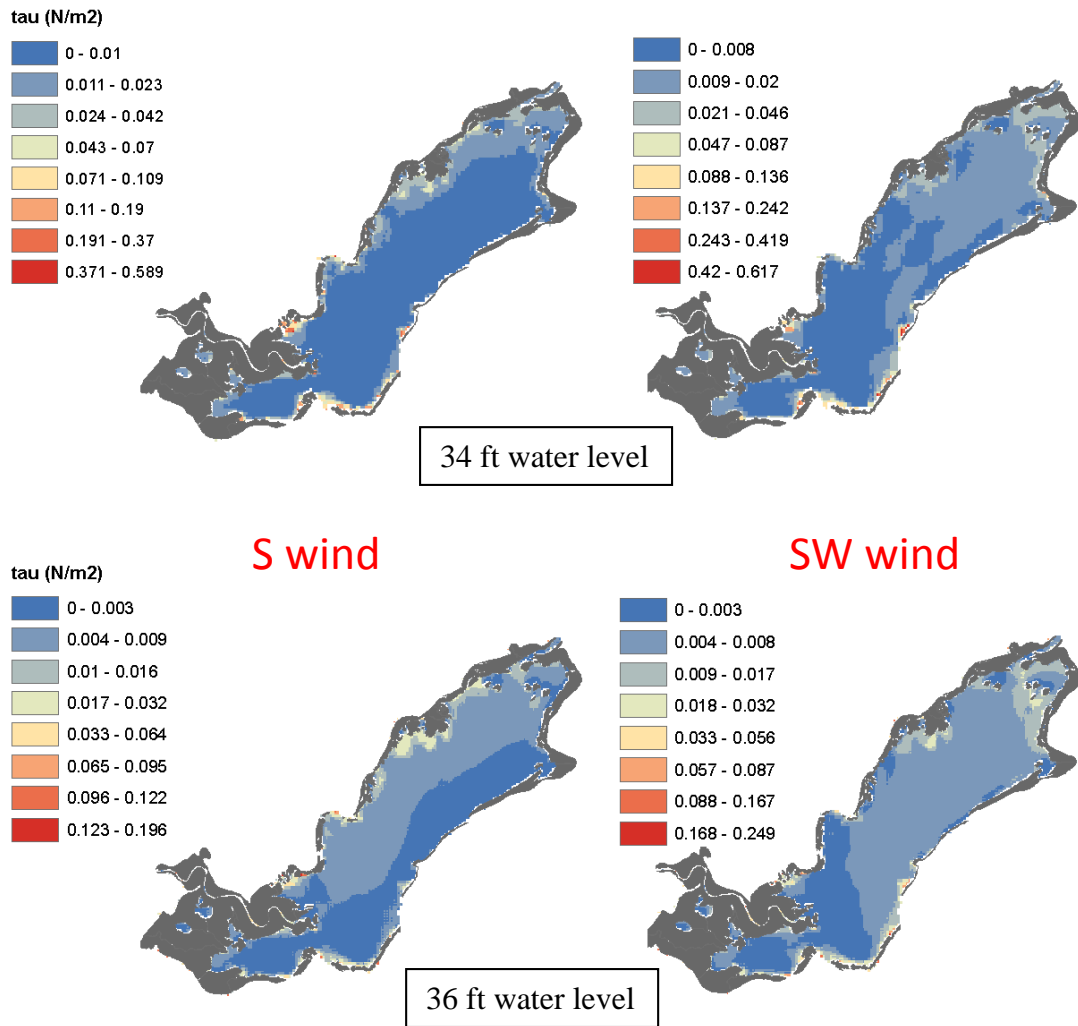**Figure 4.** *Pre- and post-canal water levels in Catahoula Lake, LA.*
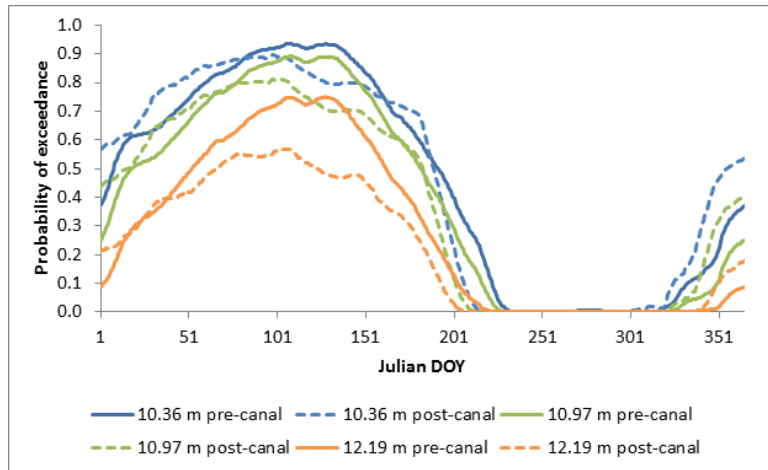
Figure 5. *Probability of exceedance for 34, 36, and 40 ft water levels for pre- and post-canal conditions at Catahoula Lake, LA.*
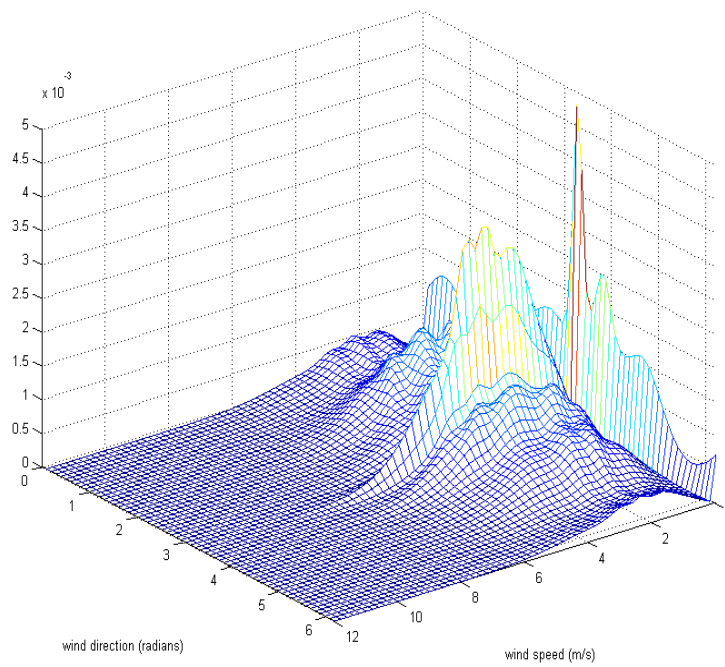
Figure 6. *Joint wind speed-direction probability distribution for June (top) July (bottom)*

Figure 7. S*hear stress for S and SW winds of 8 m/s for a duration of 1 hour for 36, bottom, and 34, top, ft water levels. Under these scenarios, shear stress is high enough to approach seedling uprooting only in isolated patches on the lake margins. However, bed mobility via resuspension is likely to occur in large areas of the lake, even the northeast end where most encroachment has occurred.*
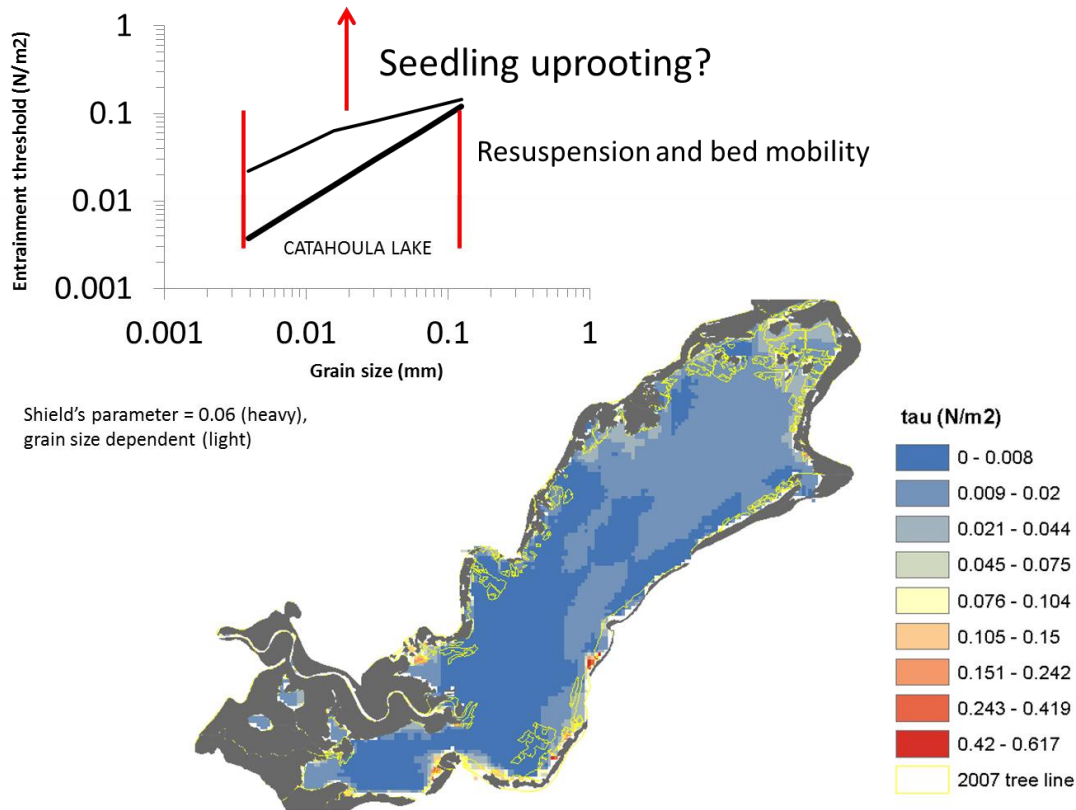
Figure 8. *The 34 ft water level, SW wind scenario overlayed with the 2007 tree line. Areas of higher stress around the lake rim appear to have experienced only gradual encroachment, if any. Also, it is apparent there is a significant increase in potential for wave stress with a relatively small decrease in water level. However, the probability of the lake remaining at or near 34 ft depth for extended periods of time when strong southerly or southwesterly winds are most probable is significantly reduced by current water management. Model runs with higher water levels predicted negligible stress for bed mobility for most of the lake.*

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Information Transfer

We are using results of this work to develop water management protocols for the lake in collaboration with the Louisiana Department of Wildlife and Fisheries.

Student Support

Megan Galbach, B.S., Mechanical & Industrial Engineering; Lincoln Dugué, M.S, Renewable Natural Resources

Information Transfer Program Introduction

None.

USGS Summer Intern Program

None.

Student Support					
Category	Section 104 Base Grant	Section 104 NCGP Award	NIWR-USGS Internship	Supplemental Awards	Total
Undergraduate	1	0	0	0	1
Masters	4	0	0	0	4
Ph.D.	2	0	0	0	2
Post-Doc.	1	0	0	0	1
Total	8	0	0	0	8

Notable Awards and Achievements

Of note in FY2014 was LWRRI's participation in response to the Deepwater Horizon Oil Spill, the largest spill in US history. Details are presented below.

LWRRI advised response agencies and conducted research on the spill:

• Dr. Pardue has also provided comments on many plans and remediation strategies ongoing through 2015

• Presented research results on two occasions to the federal on-scene coordinator in Nezw Orleans, LA

• Served on national American Petroleum Institute committee on "Use of Dispersants in the Deep Ocean"

• LWRRI Director Pardue is coordinating research and damage assessment for the Wisner Donation property in Lafourche Parish, one of the 10 largest landowners in the state. The Wisner Donation property includes 35,000 acres including Fourchon Beach. Dr. Pardue has travelled to Wisner areas to conduct research an average of once per week since October 2010

• Received research funding from LSU GOMRI BP fund and Wisner Donation

• 27 students (undergraduate, MS and PhD) have been involved in this activity to date

LWRRI research develops innovative tools for saltwater intrusion modeling:

Dr. Frank Tsai, associate professor of Water Resources Engineering in the Department of Civil & Environmental Engineering, Louisiana State University, has developed innovative tools to utilize State's well log database for visualizing and understanding saltwater intrusion in groundwater systems. Tsai and his research group are the only group that uniquely reconstructs the aquifer system underneath East and West Baton Rouge Parishes to better understand saltwater intrusion passing through a geological fault. Tsai's research, conducted in collaboration with the Capital Area Ground Water Conservation Commission of Louisiana, is a major achievement in managing groundwater resources. His research results can be found in https://sites.google.com/site/franktctsai/.